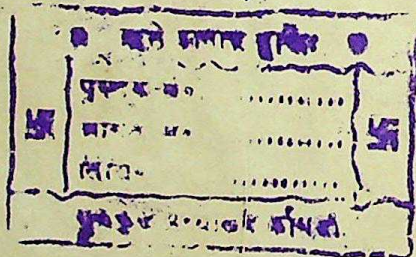




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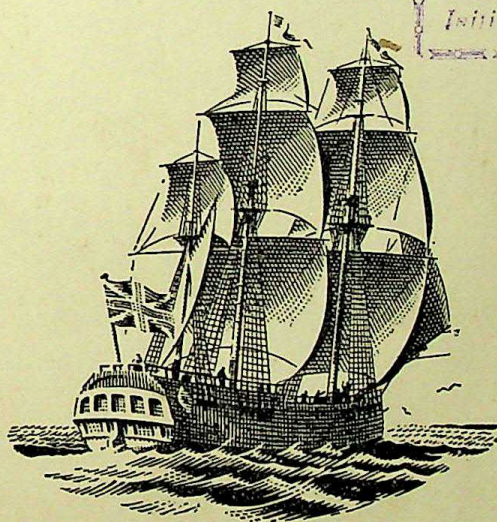
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ENDEAVOUR

A quarterly review designed to record the progress
of the sciences in the service of mankind



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Priests of Pomona

Long Ashton is a Somerset village on the outskirts of the city of Bristol. It is certainly long, and straggling, and has few pretensions to beauty. It has nevertheless achieved fame, for it is known to biologists and horticulturists the world over as the home of the Long Ashton Research Station—locally, with friendly possessiveness, just 'The Cider Institute.' Last year the Station celebrated its jubilee, and in a handsome volume recently published¹ its history and activities are described by several contributors, under the editorship of the director and a senior member of the staff.

The origin of the Station is to be found in the experiments on cider-making started in 1893 and continued until 1903 by a Somerset squire on his home farm near Glastonbury. At that time, cider-making was a crude and haphazard affair, and the product a rough though potent beverage unacceptable to most palates save by long apprenticeship. Squire Grenville was shrewd enough to perceive the possibility of transforming this harsh rustic drink into one of widespread, even national, appeal. He engaged the services of a trained analyst, whose researches on cider and its production were so successful that after some nine or ten years the government became interested. A conference was held to discuss the matter in 1902, and, after the promise of financial help from the Board of Agriculture and other sources, the National Fruit and Cider Institute was established at Long Ashton in 1903.

Though at first the Institute was very modestly housed—the original buildings consisted of a cart-shed and a fowl-house, with lofts above—its sponsors and staff had vision. One of them wrote: 'It is beginning as most things do which really last, in only a small way, but the potentialities are great, and it is hoped that its career may be one of increasing usefulness, not only in this generation but to others which are to follow.' From the outset, an admirably broad view was taken of the purposes which the Institute should serve, research and educational aspects being emphasized as much as the practical ends. Thus the staff were to investigate and demonstrate the best methods of cultivation of all kinds of fruit and vegetables; to promote and carry on research into the factors

which affect the manufacture of such fruit products as cider and perry; to improve existing varieties of fruit and vegetables and to create and introduce new varieties; and to disseminate by means of classes, lectures, or any other appropriate methods such results of investigation and research as might be likely to prove useful.

On the sound Suetonian maxim of *festina lente*, the Institute devoted most of its early energies to research on cider-making, but experimental cider-orchards and fruit-plots were established, and desirable and useful contacts were made not only with the local farmers but with the scientific staff at University College (now the University), Bristol. By these activities and by local co-operation—which manifested itself steadily throughout the year and exuberantly on the annual cider-tasting day—the Institute so strengthened its position that in 1912 the government selected it to serve as one of the newly established Agricultural Research Institutes, on condition that it became formally associated with the University of Bristol. As a result of these changes, the director of the Institute became professor of agricultural biology in the University and head of the department of agriculture and horticulture; at the same time the title of the Institute was altered to its present one of the Long Ashton Research Station.

In the period between 1912 and 1953 the Station maintained vigorous progress, and new accommodation had to be added at frequent intervals. Instead of a cart-shed and a fowl-house, there are now several well equipped specialist laboratories, together with a good library, a plant nutrition unit with special equipment for sand-purification and water-distillation, a model cider-factory, greenhouses, workshops, farm buildings, and stores. Moreover, with the multiplication of agricultural stations in various parts of Britain, some of the work with which the Long Ashton Station had burdened itself during the stress of two wars was transferred elsewhere, and the Station is again able to devote itself to the more intensive study of the subjects for which it was originally designed. Its various sections now deal with cider and fruit products, fruit-tree nutrition, pomology, plant-breeding, mycology, entomology, chemistry of insecticides and fungicides, and the culture of willows. A special unit of the Agricultural Research Council, dealing with problems of the mineral nutrition of crops, is also attached to Long Ashton.

¹ 'Science and Fruit: Commemorating the Jubilee of the Long Ashton Research Station,' edited by T. Wallace, C.B.E., F.R.S., and R. W. Marsh, M.A. University of Bristol, 1953. 30s. net.

In a foreword to 'Science and Fruit,' Sir Winston Churchill writes 'More food is needed everywhere in the world, and we in these islands must remain leaders in scientific research into problems of food production. By its past achievements Long Ashton is known wherever these problems are studied.' Those achievements have indeed been weighty and distinguished, and we cannot do more here than briefly refer to a few of them.

First and foremost, because Squire Grenville's foresight was its *fons et origo*, it may be stated that Long Ashton has been the principal agent in converting cider-making from a farm-house and small factory occupation into a large and highly organized industry. This conversion was rendered possible only by careful research into all phases of cider manufacture—from the growing of the apples to the market qualities of the finished product, from the action of bacteria in causing spoilage to the relation between the nitrogen content of apple-juice and the rate of fermentation. In the course of the investigations much new knowledge of theoretical interest has emerged on such subjects as the activities of the organisms involved and the nature of the chemical reactions taking place.

In the field of plant nutrition, one of the most noteworthy of the discoveries made at the Long Ashton Station was that the pathological condition in trees known as 'leaf scorch' is caused by a deficiency of potassium. The application of this knowledge had extremely beneficial effects upon fruit-production, for it enabled thousands of trees regarded as failures to be restored to healthy growth, and large areas of land hitherto considered unsuitable for fruit-growing to be successfully used for this purpose. Methods of visual diagnosis of nutrient deficiencies and excesses were worked out for fruit crops, and later applied to farm and market-garden crops; they were supplemented by other rapid methods, including the use of *Aspergillus niger* for the determination of macro- and micro-nutrients in soils and plant-tissue homogenates and extracts.

The problem of the control of pests and diseases of fruit is one which has engaged the attention of many workers, both in Britain and overseas. Long Ashton has played a worthy part in this field, not only by research upon insecticides and fungicides, but by developing efficient fruit-spraying methods and machinery. As a result of work at this and other stations, it is now possible to control most of the important pests of fruit in Britain, and many of the serious diseases, provided that suitable sprays are selected and adequately applied.

A special section at the Long Ashton Research Station is concerned with the scientific aspects of domestic fruit, meat, and vegetable preservation, such as a determination of the minimum temperatures required to destroy spoilage micro-organisms at the pH values of different fruits, the inactivation by heat of enzyme systems, and the retention of vitamins, particularly ascorbic acid (vitamin C). It was discovered at the Station as long ago as 1915 that apple pomace, a by-product in the manufacture of cider, contains a high proportion of pectin—an important setting-factor in jams—and this is now the main source of supply of pectin in Britain.

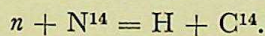
Owing to vagaries of climatic and other conditions, it often happens that cross-pollination of fruit-plants is inadequate, with consequent loss of crop. Research has therefore been undertaken by many workers with the object of trying to induce parthenocarpic development of fruit by means of growth-substances. For the tomato, many such substances are known, but experiments carried out at Long Ashton from 1942 to 1944 showed that the most useful for practical purposes is 2-naphthoxy-acetic acid. This substance, when sprayed on to the flower trusses at concentrations of 40–60 parts per million of solution, will induce fruit-set without deforming the foliage, and the fruits produced are of good quality. Growers were not slow to take advantage of this discovery, both for early glasshouse tomatoes and for outdoor tomatoes in poor seasons; full crops of fruit can now be ensured even when conditions for natural fruit-set are unfavourable. 2-Naphthoxy-acetic acid may also be used for spraying strawberries when pollination is defective; a single spray of 20 parts per million has been known to increase the crop by as much as 940 lb per acre. Recently there has been detected in the seeds of young apples a naturally occurring growth-substance which appears to be concerned with the June fruit-drop.

This sketch of the history and some of the achievements of the Long Ashton Research Station will show why we add our congratulations to the very many others received by the Station on the completion of its first half-century. We wish it a long and prosperous future; it will be spurred on by its successes, which will surely be many, but not unduly depressed by its failures. 'The breeding of raspberries at Long Ashton,' says 'Science and Fruit,' 'has not led to any results of practical value'; such engaging candour can well be afforded by a station with so fine a record as that of Somerset's 'Cider Institute.'

W. F. LIBBY

In this article, the basic principles of the radiocarbon dating technique are presented and discussed. In addition, evidence bearing on the validity of the absolute dates obtained is discussed. The technique of measurement is described and the types of materials acceptable for measurement are given. A partial list of the radiocarbon dates so far obtained is included.

The bombardment of the Earth by cosmic radiation results in the production of neutrons by the disintegration of nuclei of the air atoms. If Geiger counters are sent aloft in balloons one observes [1] that the neutron intensity rises to a maximum at some 50 000 ft and then falls abruptly at higher altitudes, as though the neutrons were not present in the incident primary radiation but were produced by collisions of the primary protons and alpha-particles with the air. This supposition is reasonable since the neutron is known to be unstable, decaying with a half-life of about 13 minutes [2] to form a proton, and could hardly live long enough to traverse the great distances of interstellar space, though it could just reach the Earth from the Sun. Careful measurements made with the balloon technique have revealed an average production rate of 2.4 neutrons/cm²/sec over the Earth's surface, strong variations with latitude being averaged out [3]. As the neutrons produced by cosmic rays never reach the Earth's surface, some absorptive process must occur in the air, and the question arises of what nuclear species neutrons will produce by reaction with air. In the laboratory, oxygen is observed to be almost completely inert to neutrons, but nitrogen, the principal constituent of air, to have a strong interaction (the nuclear cross-section for thermal-energy neutrons is 1.7×10^{-24} cm²). This interaction is almost exclusively due to a single reaction:



Various other possibilities exist. One of these is the production of radioactive hydrogen (tritium) at a small fraction of the radiocarbon yield [4, 5], but the principal product of the cosmic ray bombardment of air, at least that involving neutrons as an intermediary, must be radiocarbon; we can conclude that some 2.4 radiocarbon atoms are produced each second for each square centimetre of the Earth's surface at the present time.

If this rate has obtained in times past, especially during the last several lifetimes of radiocarbon

(5568 $\pm$ 30 years half-life, or 8030 years average life), we can say with complete certainty that a sufficient store of radiocarbon must exist on the Earth for a steady-state balance to be assured; that is, there must be enough radiocarbon for exactly 2.4 radiocarbon atoms to disappear each second per square centimetre, to ensure that the rate of formation is just equal to the rate of disappearance. Therefore we can calculate with equal certainty that there should be some 80 tons of radiocarbon on the Earth. The rates of radioactive disintegrations are immutable, and under no conditions yet obtained in the laboratory have any appreciable alterations of these rates been observed. We therefore can expect with very considerable confidence that the rate at which radiocarbon reverts to N¹⁴ by beta-decay is independent of whether it is present in a living organism or in limestone rock or as carbon dioxide in the air.

Where should one expect to find this considerable quantity of radiocarbon, and why has it not long ago been observed? Returning to the mechanism of genesis, we observe that the carbon atoms are formed at an altitude of about 6 or 7 miles on the average. It seems reasonable to suppose that the carbon atoms will burn in the air soon after their birth, to form carbon dioxide, so we conclude that the cosmic rays introduce radioactive carbon dioxide into the air, and that this is probably mixed by the winds so that all the atmospheric carbon dioxide is contaminated at the rate of 2.4 atoms of C¹⁴ per second for each cm² of the Earth's surface. However, it is of course well known that atmospheric carbon dioxide is the main source of plant carbon, through photosynthesis. Therefore we conclude that all plant life must contain radiocarbon. It is obvious also that since animal life lives on plant life it too must contain radiocarbon, and in addition the carbonate and bicarbonate and other inorganic carbonaceous materials dissolved in the sea, which are in interchange equilibrium with atmospheric carbon dioxide,

must contain radiocarbon. The total diluting reservoir apparently contains about 8.3 g of elementary carbon per cm^2 of the Earth's surface. The bulk of it is the dissolved inorganic material in the sea, which amounts to 7.25 g, and the remainder is 0.12 g of atmospheric carbon dioxide and some 0.9 g of living matter all over the Earth, together with dissolved but dead organic matter in the sea-water. Since the bulk of the reservoir is inorganic matter in the sea, which is particularly easy to determine accurately, we are entitled to assume that the total figure, 8.3, is probably accurate to about 10 per cent., even though the estimation of the total amount of living matter on the Earth is a task of great difficulty. If it be correct that there are 8.3 g of carbon involved or being mixed with the atmospheric carbon dioxide on a time-scale of the order of the 8000-year average life of radiocarbon, we can immediately calculate the specific activity of living matter to be 2.4 divided by 8.3 disintegrations per second (16.1 per minute) per gram of carbon contained. The experimentally observed value is 2.12 divided by 8.3 disintegrations per second per gram, or 15.3 per minute.

This satisfactory agreement leads us to believe that the postulate of the constancy of the cosmic radiation in the last 20 000 years or so, and the implied but not specifically stated postulate that the volume of the reservoir has not changed, are probably both correct. It would seem extremely unlikely that the cosmic ray intensity should be causally related to the volume of the sea, for two less cognate physical quantities could hardly be imagined. Therefore we may take it that, since our determination depends on the ratio, the agreement between the calculated and observed specific activity must mean that both the cosmic rays and the volume of the sea have been relatively constant for the last 10 000 or 20 000 years.

Since the cosmic ray neutron intensity varies considerably with latitude [6] one might expect living matter at the equator to be less radioactive than that in the northern and southern regions, the cosmic ray neutron intensity at 50–60° north geomagnetic latitude being some four times that at the equator. On second thought, however, one realizes that this is not likely to be so, for average radiocarbon atoms live 8000 years and therefore have this great length of time to be evenly distributed by winds and ocean currents. Direct tests have shown that this prediction is correct, and that all over the Earth's surface all forms of living matter possess the same radiocarbon activity per gram of

contained carbon to within the error of measurement.

Radiocarbon dating is based on the fact that at the time of death the assimilation of radiocarbon ceases. The radiocarbon present in the body at the time of death then proceeds to disappear at its immutable rate. Therefore, we expect that a 5568-year-old mummy or piece of tree or cloth or flesh will show one-half the specific radioactivity observed in living organic matter at the present day. The radiocarbon content of dead matter accordingly reveals the age of the specimen, the age being taken as time elapsed since death rather than, as in normal usage, time elapsed since birth. The error of measurement is determined by the accuracy with which the specific radioactivity can be measured. Direct comparison with organic matter of known age back to 5000 years, the oldest material of known age available, appears to confirm these postulates and deductions. Utilization of the method in the great periods of prehistory has resulted in a series of dates which display some element of consistency and give reason for belief in the validity of the dating technique.

METHODS OF MEASUREMENT

The radiocarbon content of living matter is so low that its measurement is difficult. The procedures used in the author's laboratory consist in the conversion of the sample to pure carbon and the measurement of the radioactivity of the latter. Pure carbon is used, since any diluent atoms will reduce the measurable effect by absorbing the very soft radiocarbon radiation. The measurement of the pure carbon is accomplished by a Geiger counter (figure 2) in which the sample of carbon lines the cylindrical wall. This places the sample in a most advantageous position, where the radiations have a high probability of being recorded. The actual probability attained with a 400 cm^2 area of carbon sample weighing 8 g in all is 5.46 per cent. Since, on the average, we find 15.3 disintegrations per minute per gram of carbon in modern organic matter, we can expect $8 \times 15.3 \times 0.0546$, or 6.7, counts per minute for modern material in our special Geiger counter.

A counter of the size used normally has a background of five or six hundred counts per minute, this background being due to laboratory contamination by naturally radioactive materials and to cosmic radiation. It is obviously necessary, therefore, that the background be reduced to a very small fraction of its normal value if we are to hope to measure the radiocarbon content of even

modern organic matter. This reduction is accomplished by the apparatus shown in figures 3 and 5. Since the background is due to two different types of radiation, namely, the cosmic rays and the natural radioactivities, we use two types of shielding. For the natural radioactivities a shield of several inches of iron is employed; this will reduce the unshielded background from 600 to 100 counts per minute. This residue of 100 counts per minute is very little reduced by the further addition of iron. As much as 20 ft seems to reduce it by only 20 or 30 per cent. It is clear, therefore, that the cosmic rays cannot be absorbed, and some device for eliminating their effect must be employed. A ring of protecting counters in close contact with one another is placed around the central Geiger counter in which the carbon sample is being measured. They are then wired so that each response in the protecting ring renders the central counter inoperative for a very small fraction of a second. Since the cosmic radiations will penetrate several inches of iron, there is little doubt about their ability to penetrate the fraction of an inch of brass or copper involved in the counter bundle, and any radiation passing through the central counter must necessarily pass through one of the shielding counters, unless it passes directly down the length of the counter. As the figure shows, we have not thought it necessary to place curtains of shielding counters at the ends. With this device the background is reduced to 5 counts per minute. One might worry about the loss of efficiency due to the fact that the central counter is turned off by the action of the protecting counters operating in anti-coincidence. The aggregate count-rate of the shielded counters when located inside the 8-in iron shield is only 900 counts per minute, and since each impulse turns off the central counter for only 1 millisecond at most one is certain that not more than one second is lost out of each minute. It is true in principle, however, that this type of shielding-arrangement has limitations if the size of the assembly is increased greatly. The advantage of putting the shielding counters within the iron shield will also be clear. It is well to note that the radiations from the radiocarbon itself will not be cancelled by the shielding counters, for they are not sufficiently penetrating to pass through the walls of the central Geiger counter. An ordinary sheet of parchment paper stops the radiocarbon radiation practically completely.

With material such as wood or peat, conversion of the samples to elementary carbon is accomplished by combustion to carbon dioxide. With

inorganic material such as calcium carbonate, acidification is sufficient to liberate carbon dioxide, which is thus produced for all types of samples. The carbon dioxide needs purification from radon, since small amounts of uranium and radium can be expected in most materials, and both the combustion and the acidification operations will carry the radon along with the carbon dioxide. The purification is accomplished by precipitating calcium carbonate and washing and drying it. The purified calcium carbonate is then acidified with hydrochloric acid and carbon dioxide is produced again. This carbon dioxide is dried and stored in bulbs. Reduction to elementary carbon is accomplished by reaction with pure magnesium metal. Magnesium turnings are placed in an ordinary iron tube about 3 ft long and 1 inch in diameter, connected to the vacuum line. The air is removed, some of the carbon dioxide is introduced, and the tube is heated to the melting-point of metallic magnesium, 651°C . At this point the reduction begins vigorously, and care must be exercised to prevent holes from being burned in the iron tube. With reasonable care the fire can be kept going until the storage bulbs are exhausted. Normally, about 1 gram-atom of carbon is involved, i.e. some 22.4 litres of carbon dioxide.

After the reduction is complete, the solid products are removed from the iron tube and extracted with hydrochloric acid, to remove the excess of metallic magnesium and the magnesium oxide produced in the reaction. This extraction takes 24 to 48 hours and produces a carbon black of about 90 per cent. purity, the remaining materials being magnesium oxide—which for some obscure reason is difficult to remove completely by hydrochloric acid extraction—and about 5 per cent. non-carbonaceous but volatile matter which may be absorbed water, or chemisorbed oxygen, or both. The samples are analysed for carbon, and appropriate correction of the observed count-rates is made.

WORLD-WIDE DISTRIBUTION OF RADIOCARBON

E. C. Anderson [7-9] studied the present distribution of radiocarbon throughout the world. As expected, the strong variation in production-rate with latitude was found to be completely masked by the long lifetime of radiocarbon and the consequent opportunity for world-wide mixing. The data given in table I show no significant variation from the mean for the woods assayed from widely scattered points on the Earth's surface. In examining

TABLE I
Activity of terrestrial biosphere samples

Source	Geomagnetic latitude	Absolute specific activity (disintegrations per minute per gram)
White spruce, Yukon	60° N	14.84 ± 0.30
Norwegian spruce, Sweden ..	55° N	15.37 ± 0.54
Elm wood, Chicago	53° N	14.72 ± 0.54
<i>Fraxinus excelsior</i> , Switzerland ..	49° N	15.16 ± 0.30
Honeysuckle leaves, Oak Ridge, Tennessee	47° N	14.60 ± 0.30
Pine twigs and needles (12 000 ft), Mount Wheeler, New Mexico ..	44° N	15.82 ± 0.47
North African briar	40° N	14.47 ± 0.44
Oak, Sherafut, Palestine	34° N	15.19 ± 0.40
Unidentified wood, Teheran ..	28° N	15.57 ± 0.34
<i>Fraxinus mandshurica</i> , Japan ..	26° N	14.84 ± 0.30
Unidentified wood, Panama ..	20° N	15.94 ± 0.51
<i>Chlorophora excelsa</i> , Liberia ..	11° N	15.08 ± 0.34
<i>Sterculia excelsa</i> , Copacabana, Bolivia (9000 ft)	1° N	15.47 ± 0.50
Ironwood, Majuro, Marshall Islands	0°	14.53 ± 0.60
Unidentified wood, Ceylon ..	2° S	15.29 ± 0.67
Beech wood (<i>Nothofagus</i>), Tierra del Fuego	45° S	15.37 ± 0.49
<i>Eucalyptus</i> , New South Wales, Australia	45° S	16.31 ± 0.43
Seal oil from seal meat from Antarctic	65° S	15.69 ± 0.30
Average		15.3 ± 0.1*

*Error of calibration of counter raises error on absolute assay to 0.5.

this table it is well to remember that, as previously mentioned, the cosmic ray intensity and, therefore, the radiocarbon production-rate are about one-fourth as great at the equator as at the latitude of 50 or 60° geomagnetic north—and, presumably, south also. The further point should be recalled that, the average life of radiocarbon being 8000 years, the radiocarbon atoms now present in living organic matter and in the dissolved carbonaceous material in the sea have been on the Earth for 8000 years on the average, and have therefore had abundant opportunity to circulate throughout the cycle of life and to be moved about in the ocean currents and in the winds of the atmosphere.

The absolute radiocarbon content thus appears to be in reasonably good agreement with the present rate of production of radiocarbon, if we assume that the ocean is mixed with radiocarbon essentially to its full depth. The amount of carbon involved in living forms on land is negligible relative to the inorganic carbon in the sea. In

other words the 2.4 atoms being produced per second per cm² on the average at the present time, when divided by the 8.3 g of carbon in the ocean and in the life cycle, agree to within 10 per cent. with the observed radiocarbon content at the present time. This plainly indicates that in the course of some 8000 years uniform mixing of the waters of the sea occurs, even at great depths—a point of much interest to oceanographers. It indicates further that the present cosmic ray intensity is not far different from that which obtained 8000 years ago. This latter point is of course vital to the radiocarbon dating method, in that we must assume that the radiocarbon content of living matter at the present time has been its content at all times, and that a piece of wood measured now has the same radiocarbon content as a comparable piece would have had in Egypt 5000 years ago. As we shall see later, there is further confirmatory evidence of this in the apparent agreement found among the radiocarbon contents of carbonaceous samples of historically known age.

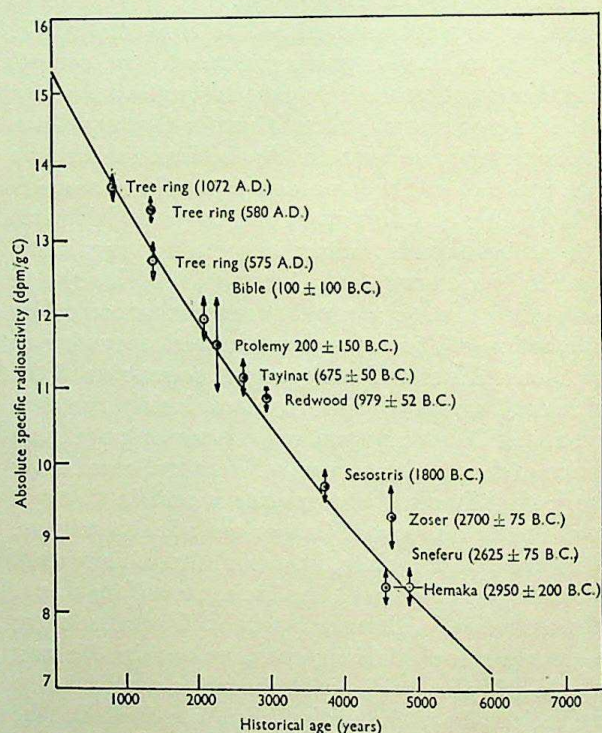


FIGURE 1—Samples of known age. The solid curve is calculated from the assay for modern wood and the laboratory measurement of the half-life of radiocarbon. The individual points are the specific radioactivities of various pieces of organic matter, principally wood, of known age. The errors indicated are the standard deviations (which ensure 2 out of 3 chances), and are calculated solely on the basis of the number of counts taken; they do not include any other errors, such as that arising from contamination.

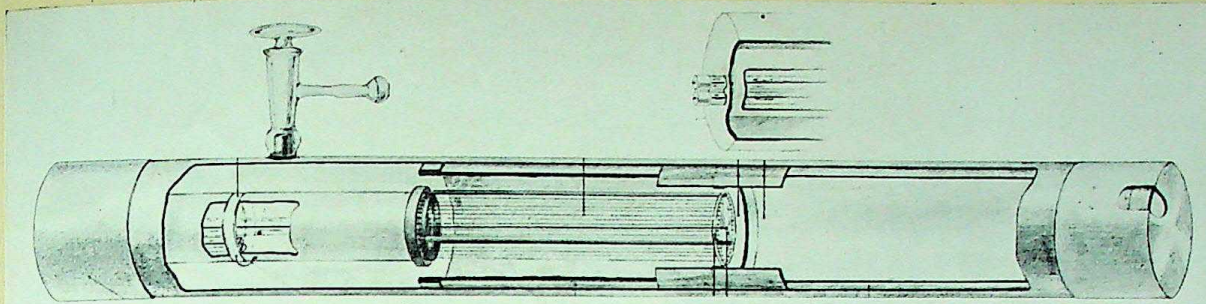


FIGURE 2 — Screen wall counter. The sample in the form of elementary carbon is disposed round the inside surface of a movable cylinder surrounding a grid, defining the sensitive Geiger counter volume. The two possible positions of the cylinder correspond to the carbon sample being alternately over the grid and removed from it, so the difference in counting-rate is a direct measure of the radiocarbon activity.

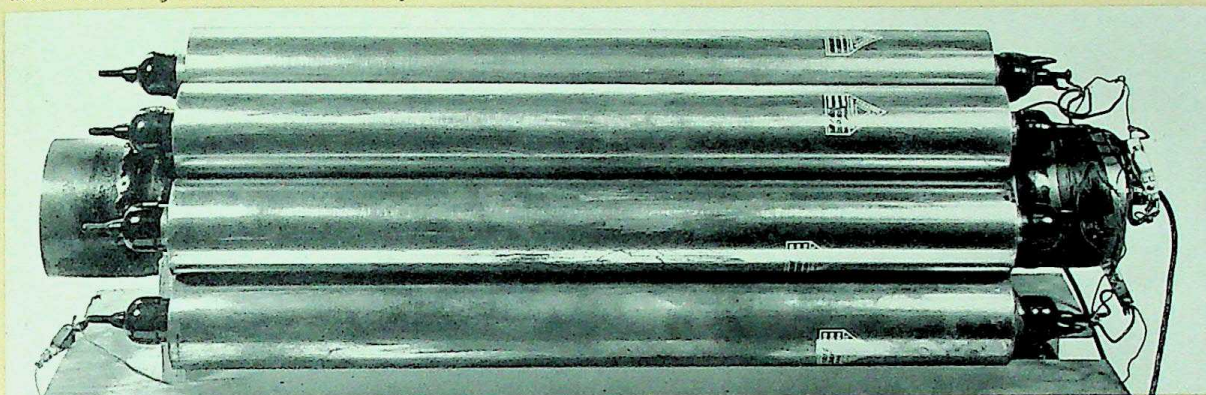


FIGURE 3 — Side view of the screen-wall counter surrounded by the shielding counters used to cancel out the penetrating cosmic rays. The box contains four counters underneath, making a total of eleven, as shown in figure 5.

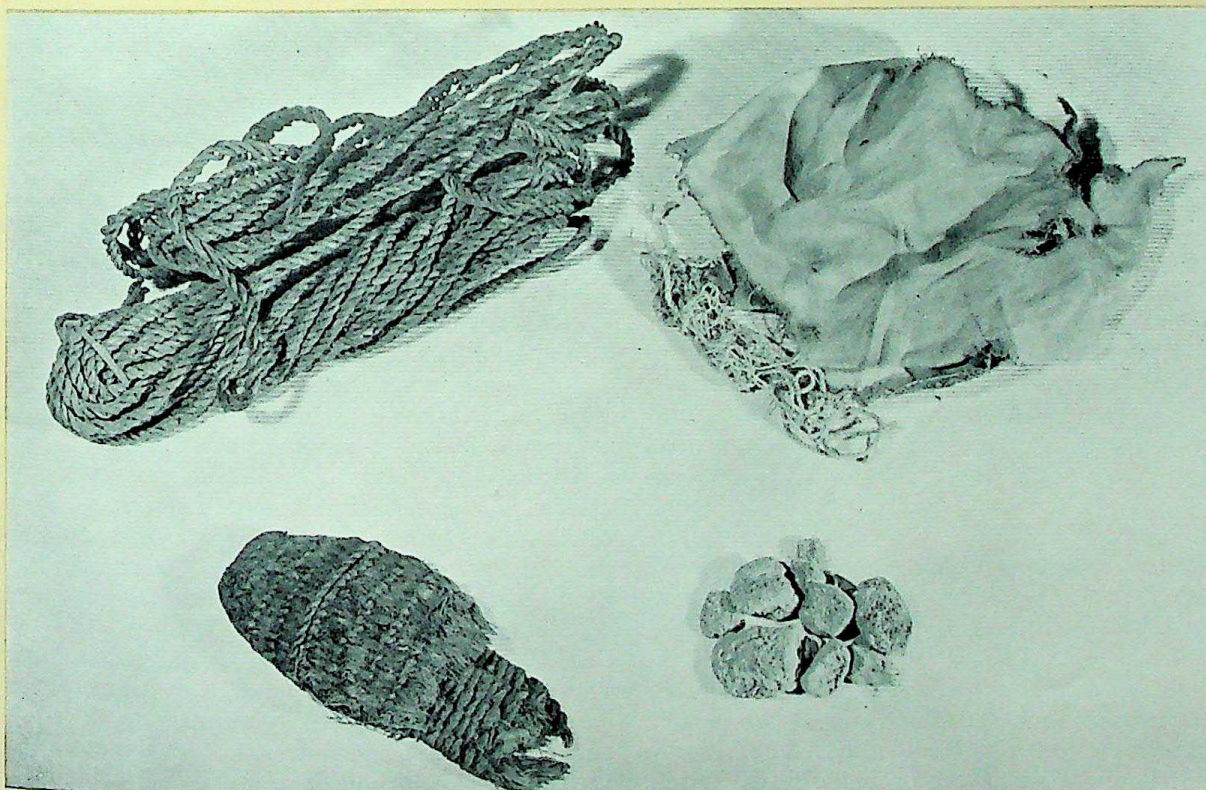


FIGURE 4 — Typical samples used for measurement. Left foreground, rope sandal from Fort Rock Cave, Oregon, 9000 years old. Left rear, 2000-year-old rope from Peru. Right rear, 2000-year-old cotton cloth from Peru. Right foreground, 10 000-year-old faeces of the extinct giant ground sloth (*Northrotherium shastense*) from Gypsum Cave, Nevada.

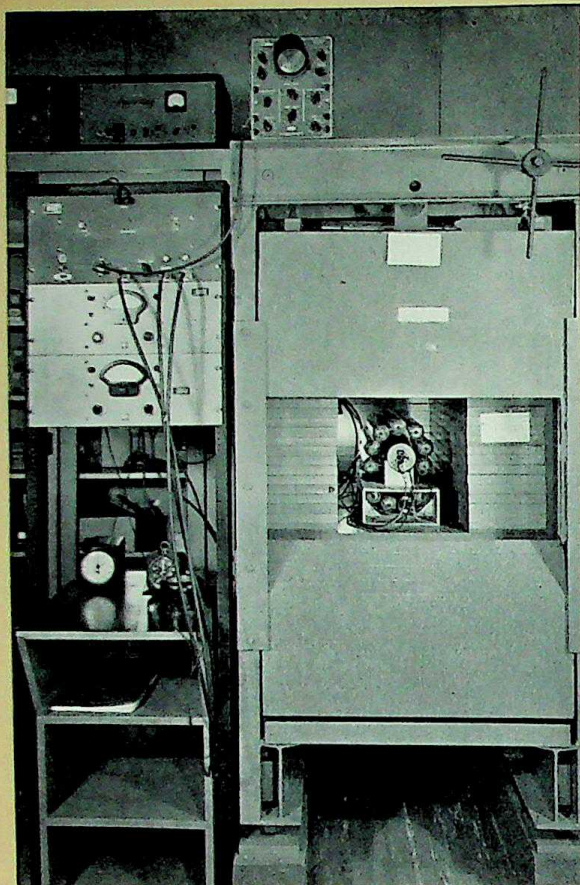


FIGURE 5 - The complete apparatus, consisting of the iron shield (with the door open), the counter bundle in place, and the associated electronic apparatus. The shield has at least 8 inches of iron in all directions and weighs some 6 tons.

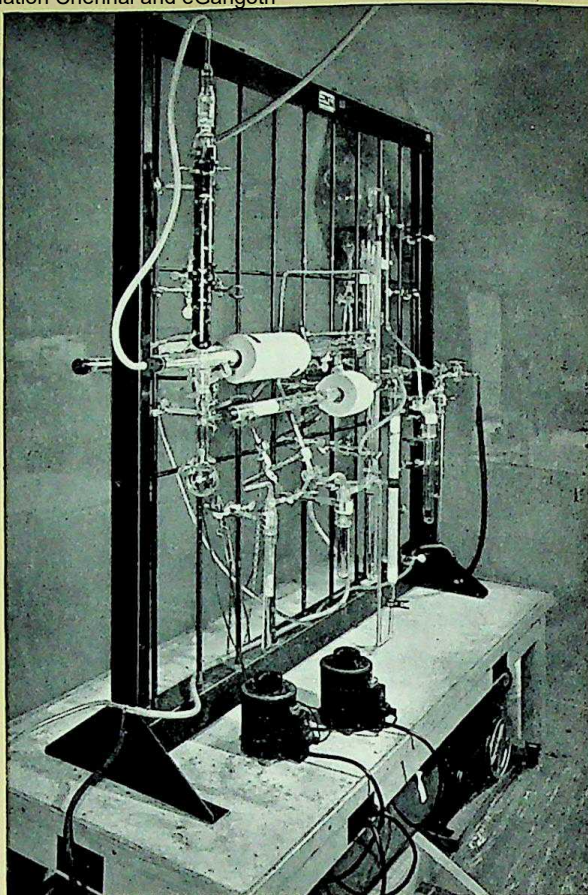


FIGURE 6 - Typical laboratory vacuum line in which the samples are burned to carbon dioxide, which is stored in bulbs; the carbon dioxide is reduced to carbon by means of metallic magnesium.

RADIOCARBON DATING

The possible utilization of natural radiocarbon for dating was one of the principal goals throughout the early stages of our research. These consisted in the discovery of natural radiocarbon in Baltimore sewage methane with A. V. Grosse and his collaborators [10], the development of the measurement techniques, and a world-wide assay. We then approached the interesting and crucial stage of testing the dating method with considerable care. J. Arnold joined the group as principal collaborator in this phase of the research. The American Anthropological Association and the Geological Society of America appointed a Committee on Carbon-14, consisting of F. Johnson (chairman), D. Collier, F. Rainey, and R. F. Flint, to advise on the selection of samples for measurement and, most important, to organize a comprehensive test of the method. The Wenner Gren Foundation for Anthropological Research, under its director P. Fejos, gave generous financial

support to the research. Part of the development of the low-level counting technique was conducted under contract with the United States Air Force.

The advisory committee decided that it would be possible to test the method against samples of known age back to about 5000 years. This was done, and the results are shown in figure 1. The curve drawn is the exponential decay curve fixed by the laboratory determination of the half-life and the world-wide assay of modern organic matter for radiocarbon (table I). The errors indicated are standard errors as determined solely by the counting-statistics. That is, they are essentially governed by the square root of the total number of counts measured. Experience has indicated that this is the principal source of random error in the measurement, in that repeated measurements on a given sample have shown scatter not inconsistent with this single measure. The materials used as samples of known age are given in table II.

It is clear that with one or two exceptions the

TABLE II
Samples of known age

Sample No.	Description	Age (years) by C ¹⁴ dating
108A	<i>Sequoia</i> trunk, clean borings in growth-rings between year A.D. 1057 and 1087, i.e. known age 880 ± 15 years.	800 ± 600 900 ± 200 1030 ± 200 900 ± 200 Av. 930 ± 100
103	<i>Broken Flute Cave, New Mexico (Tree Ring)</i> . Douglas fir wood excavated in 1931 from Red Rock Valley, Room 6, Broken Flute Cave. Inner ring, A.D. 530; outer ring, A.D. 623. Known age thus 1330-1423 years.	973 ± 200 1070 ± 100 Av. 1042 ± 80
108B	<i>Sequoia</i> trunk (108A), rings A.D. 570-578, i.e. known age 1377 ± 4 years.	1520 ± 170 1300 ± 200 Av. 1430 ± 150
576	<i>Bible</i> . Dead Sea scrolls. Book of Isaiah; linen wrappings used. Found in cave near Ain Fashkha in Palestine. Thought to be first or second century B.C.	1917 ± 200
62	<i>Ptolemy</i> . Wood from mummiform coffin of Egyptian Ptolemaic period. Age 2280 years, according to John Wilson.	2190 ± 450
72	<i>Tayinat</i> . Wood from the floor of a central room (I-J-1st) in a large hilani ('palace') of the Syro-Hittite period in the city of Tayinat in north-west Syria. Age 2625 ± 50 years, according to R. J. Braidwood.	2696 ± 270 2648 ± 270 2239 ± 270 Av. 2531 ± 150
159	<i>Sequoia</i> . Wood from the heart of the giant redwood known as the 'Centennial Stump,' felled in 1874, with 2905 rings between the innermost, and 2802 rings between the outermost, portion of the sample and the outside of the tree. Therefore known age was 2928 ± 51 years.	3045 ± 210 2817 ± 240 2404 ± 210 Av. 2710 ± 130
81	<i>Sesostris</i> . Wood from deck of funerary ship from tomb of Sesostris III. Age 3750 years, according to John Wilson.	3845 ± 400 3407 ± 500 3642 ± 310 Av. 3621 ± 180
1	<i>Zoser</i> . Acacia wood beam in excellent state of preservation from tomb of Zoser at Sakkara. Age 4650 ± 75 years, according to John Wilson.	3699 ± 770 4234 ± 600 3991 ± 500 Av. 3979 ± 350
12	<i>Sneferu</i> . Cypress beam from tomb of Sneferu at Meydum. Age 4575 ± 75 years, according to John Wilson.	4721 ± 500 4186 ± 500 5548 ± 500 4817 ± 240 Av. 4802 ± 210
267	<i>Hemaka</i> . Slab of wood from roof beam of tomb of the vizier Hemaka, contemporaneous with King Udimu, Dynasty I, at Sakkara. Accepted age 4700-5100 years, according to Braidwood.	4803 ± 260 4961 ± 240 Av. 4883 ± 200

With the exception of samples 108A and 108B, which were determined by J. L. Kulp and his group at Columbia University [11], the data are to be found in the author's book 'Radiocarbon Dating' [9].

TABLE III
Radiocarbon Dates

Sample No.	Description	Age (years)
I. MESOPOTAMIA AND WESTERN ASIA		
A. EGYPT		
1, 12, 62, 81, 267	<i>Cf. Table II.</i>	
463	<i>Middle Predynastic.</i> Charcoal from point A-15 of the house floors at El-Omari near Cairo, Egypt. A typological assessment of the position of El-Omari would be about midway between the time of the Upper K pits of the Fayum (Nos 457, 550, and 551) and Hemaka (No 267).	5256 ± 230
C-753	<i>Shaheinab charcoal.</i>	5060 ± 450
C-754	<i>Shaheinab shell.</i> Bivalve shells from Shaheinab, apparently in fairly unaltered condition. This ancient site may provide a clue to whether some elements in Egyptian civilization came from Africa northward. The site is about 1200 miles from the Egyptian Fayum (samples 457, 550, 551—the Egyptian granaries, which dated 6240 years), and the archaeological connection with the Fayum Neolithic is close.	5446 ± 380
457	<i>Fayum A (Upper K).</i> Wheat and barley grain uncarbonized with no preservatives added, from Upper K Pit 13 of the Fayum A material.	6054 ± 330 6136 ± 320
		Av. 6095 ± 250
550 and 551	<i>Fayum A (Upper K).</i> Wheat and barley grain from Upper K pit 59, Jar 3, and another of the Upper K pits (number lost) of the Fayum A material.	6391 ± 180
B. IRAQ		
113	<i>Jarmo.</i> Land-snail shells fairly well preserved from the basal levels 7 and 8 at Jarmo.	6707 ± 320
C-742	<i>Jarmo (Jarmo II).</i> Charcoal. Jarmo is an early village site midway between the towns of Kirkuk and Sulimaniyah. This site is Early Neolithic and exhibits the earliest traces of an established food-producing village economy in the Near East. Only the upper third of the site yielded portable pottery. An excavation labelled I was made clear to virgin soil near one edge of the mound. Eight floors were found. A second excavation, labelled II, was made at the highest point. This went down 4 m through the sixth floor, which is still 3.2 m above virgin soil. The sixth floor of II is equivalent to the third floor of I, and the second floor of II is equivalent to the first floor of I. The earlier Jarmo sample (113), consisting of shell, came from the seventh floor of I.	6606 ± 330
C-743	<i>Jarmo (Jarmo III).</i> Charcoal from fifth floor of excavation II (<i>cf.</i> samples 742 and 113).	6695 ± 360
II. WESTERN EUROPE		
A. FRANCE		
406	<i>Lascaux.</i> Charcoal from the Lascaux cave in the Dordogne.	15516 ± 900

TABLE III (continued)

Sample No.	Description	Age (years)
B. GERMANY		
337	<i>German Allerød.</i> Peat with birch remains from Pollen Zone IIb, the younger Allerød, from Wallensen-im-Hils, north-western Germany.	11 044 ± 500
C. DENMARK		
432	<i>Danish Boreal (Danish Boreal II).</i> Pine cones from Denmark. They are from pollen zone V, thought to be 8500 years old.	7583 ± 380
433	<i>Danish Boreal (Boreal IV).</i> Hazel-nuts from Denmark. The nuts are from one single summer dwelling, belonging to the late boreal age, pollen zone VI, thought to be about 8000 years old.	9935 ± 440 9927 ± 830 Av. 9931 ± 350
434	<i>Danish Boreal (Danish Boreal III).</i> Charcoal from the same summer house as No 433. Expected age about 8000 years.	8631 ± 540
435	<i>Danish Boreal (Danish House).</i> Birchwood from the same area as Nos 433 and 434. From House 2. Probably a few years younger than House 1.	9425 ± 470
D. IRELAND		
355	<i>Irish mud.</i> Lake mud from Knocknacran, County Monaghan. Late Glacial, pollen zone II.	11 310 ± 720
356	<i>Irish Post-glacial.</i> Lake mud, Lagore, County Meath. Early Post-glacial, Zone IV.	11 787 ± 700
E. ENGLAND		
353	<i>Yorkshire.</i> Wooden platform from Mesolithic site at Lake Pickering. Pollen zone IV.	10 167 ± 560 8808 ± 490 Av. 9488 ± 350
444	<i>Neasham.</i> Lake mud from Neasham, near Darlington. Pollen zone II, correlated directly with last Glacial stage.	10 851 ± 630
341	<i>Hawks Tor.</i> Peat from Hawks Tor, Cornwall, late Glacial, pollen zone II, 9 ft to 9 ft 4 in at site 1, middle of lower peat.	9861 ± 500
602	<i>Stonehenge.</i> Charcoal sample from Stonehenge, Wiltshire. Late Neolithic.	3798 ± 275
F. ICELAND		
C-749	<i>History of the Geomagnetic Field, Reykjavik, Iceland (Iceland Peat).</i> The direction of the Earth's magnetic field is recorded by solidifying lava, at the time of solidification, by the permanent polarization of the lava. Near Reykjavik, a lava flow occurs with polarization roughly parallel to the present geomagnetic field. It happened to flow over Post-glacial peat, which constitutes the sample. Its date correlates directly with that of the flow.	5300 ± 340

TABLE III (continued)

Sample No.	Description	Age (years)
III. UNITED STATES		
A. LOUISIANA, MISSISSIPPI, NEBRASKA, AND TEXAS		
558	<i>Folsom Bone.</i> Burned bison bone from Lubbock, Texas, from the Folsom Horizon.	9883 ± 350
B. ARIZONA, CALIFORNIA, AND NEW MEXICO		
440 and 522	<i>California Early Horizon.</i> Charcoal from near Sacramento, site SJo-68; culture Early Central California Horizon.	4052 ± 160
C-631	<i>California Crude I.</i> Crude oil taken from depth of 1100 ft in the Tulare formation, Upper Pliocene age, at the South Belridge field, California.	Older than 24 000
C-632	<i>California Crude II.</i> Crude oil from the upper or middle Pico formation, Upper Pliocene age, from the Padre Canyon field, California. This, and sample 631, constitute the youngest crude oil samples measured.	Older than 27 780
C. NEVADA, OREGON, AND UTAH		
221	<i>Gypsum Cave.</i> Dung of giant sloth (figure 4) from Gypsum Cave, Las Vegas, Nevada. Collected in 1931 from room 1, dung layer 6 ft 4 in from surface.	10 902 ± 440 10 075 ± 550 Av. 10 455 ± 340
599	<i>Leonard Rock guano.</i> Bat guano taken from immediately next to the Pleistocene gravels in the Leonard Rock Shelter, Nevada.	11 199 ± 570
298	<i>Leonard Rock Shelter (Leonard Rock II).</i> Atlatl (throwing-stick) foreshafts of <i>Sarcobatus</i> , greasewood.	7038 ± 350
247	<i>Mazama, Oregon.</i> Charcoal from a tree burned by the glowing pumice thrown out by the explosion of Mount Mazama (this formed Crater Lake). The pumice is about 75 ft deep at this point, and about 40 ft of pumice overlies the portion of the tree from which these samples came. The impression was that the tree was still very nearly in an upright position.	6389 ± 320 7318 ± 350 5938 ± 400 6327 ± 400 Av. 6453 ± 250
428	<i>Fort Rock Cave, Oregon.</i> Several pairs of woven rope sandals (figure 4) found in Fort Rock cave, which was buried beneath the pumice from the Newberry eruption in Oregon.	9188 ± 480 8916 ± 540 Av. 9053 ± 350
609	<i>Danger Cave I, Utah.</i> Charcoal, wood, and sheep-dung from Danger Cave, near Wendover.	11 453 ± 600
610	<i>Danger Cave II.</i> Same as No 609, wood.	11 151 ± 570
C-611 and C-635	<i>Danger (Lamus) Cave.</i> Floor of cave was dated at 11 453 ± 600 and 11 151 ± 570 years by sheep-dung and wood fragments respectively, which were found in the sand (samples 609 and 610).	
C-611	<i>Danger Cave III.</i> Charcoal from just above the sand in the lowest layers of the 15 ft deposit of garbage and debris found at the cave mouth.	9789 ± 630
C-635	<i>Danger Cave VII.</i> Charred bat guano, plant stems, and twigs from 18 to 24 in below the current surface of the pile of debris.	1930 ± 240

TABLE III (continued)

Sample No.	Description	Age (years)
D. MINNESOTA, WISCONSIN, AND WYOMING		
308	<i>Two Creeks.</i> Wood and peat samples from Two Creeks forest bed, Wisconsin. Forest bed underlies Valder's Drift (Thwaites). Apparently the spruce forest was submerged, pushed over, and buried under glacial drift by the last advancing ice sheet in this region. Thought to be Mankato in age.	
365		
366		
536		
537		
	<i>Sample</i>	
	308 (spruce wood)	10 877 $\pm$ 740
	365 (tree root)	11 437 $\pm$ 770
	366 (peat in which root, 365, was found)	11 097 $\pm$ 600
	536 (spruce wood)	12 168 $\pm$ 1500
	537 (peat)	11 442 $\pm$ 640
		Av. 11 404 $\pm$ 350
C-630	<i>Kimberly, Wisconsin (Neenah).</i> Glacial wood from Kimberly, Wisconsin. This consisted of a tree stump about 9 ft $\times$ 5 ft, found about twelve years ago. The site is almost in a direct line with the Pointe Beach site of Two Creeks, and is thought to be of Mankato age (cf. samples 308, 365, 366, 536, 537, 444, and 355-7).	10 676 $\pm$ 750
302	<i>Sage Creek, Wyoming (Yuma).</i> Partially burned bison bone with high organic content.	6619 $\pm$ 350 7132 $\pm$ 350
		Av. 6876 $\pm$ 250
IV. SOUTH AMERICA		
484	<i>Mylodon Cave, Chile.</i> Dung of giant sloth from Mylodon Cave, Ultima Esperanza, Chile (51° 35' S). Not associated with human artifacts, though sloth and man were found together in three caves 125 miles distant (cf. No 485).	10 800 $\pm$ 570 10 864 $\pm$ 720
		Av. 10 832 $\pm$ 400
485	<i>Palli Aike Cave, Chile.</i> Burned bone of sloth, horse, and guanaco, associated with human bones and artifacts.	8639 $\pm$ 450
V. OTHER AREAS		
548	<i>Japanese.</i> Charcoal from Ubayama shell mound, about 10 miles west of Tokyo. Charcoal was part of structural remains in a house area in the bottom levels of the mound. Thought to be oldest house site in Japan.	4850 $\pm$ 270 3938 $\pm$ 500
		Av. 4546 $\pm$ 220
603	<i>Late Jomon.</i> Charcoal from the early Late Jomon (Horinouchi Stage) Horizon at the Ubayama shell mound (cf. No 548), Japan.	4513 $\pm$ 300
C-613	<i>Zimbabwe.</i> Large log from the famous prehistoric site of Zimbabwe in southern Rhodesia. Zimbabwe is generally thought to date from the fourteenth or fifteenth centuries A.D., but may be as early as the ninth century A.D.	1415 $\pm$ 160 1344 $\pm$ 160 1271 $\pm$ 260
		Av. 1361 $\pm$ 120
C-669	<i>Chalan Piao Site, Saipan Island (Saipan).</i> Oyster shell found 1.5 ft below the surface at the Chalan Piao Site, about $\frac{1}{2}$ mile inland from the shore line. Conjectural date, 3000-4000 years.	3479 $\pm$ 200
C-721	<i>Blue Site, Tinian Island (Tinian Blue Site).</i> Shell (<i>Tridacna</i>) from the Blue Site on Tinian in the Marianas Islands, from Test A at a depth of 1.9 ft.	1098 $\pm$ 145

All published dates are contained in the references 9, 11, 12, and 13.

agreement is satisfactory. These exceptions may be acceptable statistically and we need not dwell on them in this short article. One of the most interesting of the 'knowns' is the redwood sample. This giant tree apparently has heartwood still containing the carbon originally deposited there when the wood was formed. This result—very acceptable to most botanists, we understand—seems to be somewhat astonishing chemically. The fine filaments which constitute the cell walls, though made of cellulose molecules which of course are extremely inert, have been bathed for thousands of years with enzymatically active sap.

The radiocarbon deposited at the beginning of history still has more than half the modern assay, so it was obviously necessary to consider how the great periods of prehistory could be used to check the method, and *vice versa*. The committee attacked this problem by setting up a network of projects so designed as to afford the maximum number of internal cross-checks. They arbitrarily excluded certain areas of the world and periods of history in order the more to concentrate, temporally and geographically, the prehistoric problems being investigated. They then assembled a team of collaborators in geology and archaeology, who proceeded to furnish samples for the study. The results now number nearly 400, including those obtained at other laboratories, though the committee has been advisory to our group alone. It is impossible in this short review even to list all the dates, but some of the more interesting ones are given in table III.

It is somewhat difficult to judge the significance of this group of dates. It seems that one of the principal conclusions is that the ice last covered both North America and Europe some 11 000

years ago. We see this in the Wisconsin Two Creeks Forest results (sample numbers 308, 365-6, 536-7 and C630), and in the European dates 337 for Germany, 355 and 356 for Ireland, and 444 for England. It would seem that there is some evidence that the northern regions of Europe and of North America were covered simultaneously.

It is interesting that, according to radiocarbon evidence, the earliest men in North America, Britain, and Denmark appeared roughly contemporaneously some ten thousand years ago. We were afraid that we should find man older than the last ice age, and had agreed that this would constitute sufficiently conclusive evidence to discredit the whole method; we felt that glaciers sweep very clean and that there should be no evidence of earlier human occupation left. So in England, which was completely glaciated, there should be no evidence of human beings older than the time of the last ice sheet. One notes that the Lascaux cave (Dordogne), sample 406, apparently was occupied, and that its paintings were executed, some 5000 years before the last ice sheet. Other samples not listed have revealed the existence of man around the Mediterranean basin long before the last ice sheet. Such evidence has not appeared in the Americas. This may of course be a fortuitous circumstance, but it does seem significant that abundant evidence of the 10 000-year threshold appears.

The ultimate question of the validity of the absolute dates given by the radiocarbon method is not yet completely answered. The evidence seems to be somewhat favourable, but only the passage of time, with its further accumulation of dates and its further digestion of the results obtained, can furnish us with a final answer.

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Jean Picard and his circle

A. ARMITAGE

The achievements of Jean Picard added lustre to the earliest years of the Academy of Sciences and the Paris Observatory. A pioneer in the use of the filar micrometer, he was also one of the first to develop telescopic sights, which he employed in geodetic operations to determine the size of the Earth with unprecedented accuracy. While in quest of the longitude of Tycho Brahe's former observatory, Picard made another notable discovery, that of the young Danish astronomer Ole Rømer, whom he launched upon a fruitful scientific career.

Among the most significant developments in seventeenth-century Europe was the rise of the scientific societies in which the pioneers of the new experimental philosophy banded themselves together for co-operative research. Two of these organizations, the Royal Society of London and the French *Académie Royale des Sciences*, attained lasting pre-eminence, and it is with one of the outstanding personalities of the latter foundation that this study is chiefly concerned. Jean Picard was the central figure of a group of inventors and observers, some of them drawn from beyond the frontiers of France, whose achievements greatly advanced precise astronomy during the later decades of the 'century of genius.'

Of Picard's life-story little is known beyond what is to be gathered from his published works. He was born at La Flèche, in Anjou, on 21st July, 1620. He took orders and bore in later life the titles of *Abbé* and *Prieur*. His earliest role in science seems to have been that of assisting in the astronomical observations of Pierre Gassendi (or Gassend), famous in the history of thought for his attempt to revive, in a Christian setting, the ancient doctrine of atomism. Although Gassendi himself could claim no notable astronomical discovery, for many years he continued the practice of methodically observing all classes of celestial phenomena. More than one operator was required to handle the cumbrous instruments of those days, and in his journal of observations, under the date 21st August, 1645, Gassendi records a solar eclipse which he observed with the assistance of 'the studious and learned Joannes Picardus of Anjou.' The budding astronomer is mentioned again for services rendered at lunar eclipses in 1646 and 1647 [1], but Picard's most productive years were those which he spent, when past middle life, as one of the distinguished company of the Academy of Sciences.

Among his schemes for enhancing the glory of

France, Colbert, the prime minister of Louis XIV, had included the creation of an institution designed to embrace all branches of learning. However, various specialist groups preferred to form associations of their own, leaving a mixed band of mathematicians and physicians (which included chemists and naturalists) to constitute, in 1666, the new Academy of Sciences appointed to meet regularly in the Royal Library [2] (figure 3). Among the pioneer Academicians, Picard and two others, Auzout and Huygens, seem to have formed a closely knit group with predominantly astronomical interests. Adrien Auzout, a native of Rouen, had already played a prominent part in the informal discussion groups which had been a feature of Parisian intellectual life for a generation, and he rivalled Picard in attainment. Christiaan Huygens, one of the greatest scientists of the day, was well known in Paris from previous visits when he arrived there by invitation from his native Holland in the foundation year. These three used at first to observe the heavens from the gardens of the Royal Library. The annals of the Academy and the *Histoire Céleste* covering these early years (1666-85) have much to tell us of the problems and technical experiments that preoccupied Picard and his colleagues [3].

Much attention was devoted to the accurate measurement of the apparent diameters of the heavenly bodies. It was for work of this kind that the filar micrometer was introduced, in a form not essentially different from that which it assumes today. It appears to have been independently invented by Hooke and by Auzout, who both described it in 1667, but Picard had a share in the development of the design and became expert in its use. The instrument consisted of two metal frames, each carrying a number of parallel hairs, one frame sliding over the other in the common focal plane of the object-glass and eye-piece of the telescope to which the micrometer was fitted. This

frame was moved by turning a screw. In order to measure, say, a planetary disk, the image of the latter was confined between two hairs (one from each set), the distance between the hairs being expressed as so many turns of the screw and some fraction of a turn, these arbitrary units being subsequently converted into angular measure [4]. Picard and Auzout made almost daily use of the micrometer to measure the angular diameters of the Sun and Moon, protecting their eyes with coloured or smoked glasses. It had been a favourite exercise of Picard's master, Gassendi, to investigate how refraction affects the Sun at various meridian altitudes, and the Parisian astronomers were among the first to recognize that this factor is operative right up to the zenith, not ceasing at some arbitrary altitude as had formerly been supposed. On the other hand, the results of measuring the Moon's angular diameter throughout an entire lunation tended to undermine the currently accepted lunar theory. Eventually, the Academy became dissatisfied with all existing astronomical tables, and resolved to construct new ones from fundamental observations. The ambitious programmes of observation drawn up by the Academicians created a demand for instruments capable of measuring angles (larger than those amenable to the micrometer) with much greater precision than had hitherto been possible. This want was supplied by Picard's use of telescopic sights, which increased the accuracy of observation some sixty-fold. Such sights had been suggested by Hooke about 1665, and he says that in that year he was using an instrument of Sir Christopher Wren's invention, with telescopic sights, for examining the motion of a comet. It is possible that Picard had not heard of Hooke's work, and that the telescopic sights he used were of his own invention.

Earlier workers had been accustomed to measure celestial angles by means of instruments typified by a large graduated circle or arc, carrying a radial pointer, or alidade, which they directed towards any selected object with the aid of a pair of primitive sights. For these sights Picard substituted a telescope equipped with crossed hairs in the focal plane, thus greatly reducing the uncertainty with which the directions of objects could be defined and the angles between them measured. It now appears that this revolution was effected in two stages [5]: first, the use of a pair of convex telescope lenses which were attached to (or substituted for) the sights of the older type of instrument; and next, when these

were seen to constitute a tubeless telescope, the attachment of a complete telescope, tube and all, to the instrument, with two hairs crossed at the common focus. One obvious application of this invention was to fix such an instrument to a wall with its graduated arc in the plane of the meridian, and to utilize it for taking the time and the altitude of meridian transit of celestial objects. Picard indeed asked the authorities to set up a meridian quadrant for him, but, according to Grant's 'History of Physical Astronomy,' the request was not fulfilled.

Astronomical measuring instruments could now be made much smaller than formerly, to fit telescopes two or three feet in length. The first of them were ready by early in 1669, and it was, significantly, in that year that Picard set about obtaining an improved estimate of the length of a degree of meridian on the Earth's surface, a quantity from which the size of the Earth can be immediately deduced [6].

Picard followed the classic procedure of determining the meridian zenith distance of a selected star (in Cassiopeia) from each end of a meridian arc of measured length; the difference between the two angles (giving the difference of latitude of the two observing stations) bore the same proportion to 360° as the length of the arc bore to the Earth's circumference, which was thus calculable. Applications of this method had been made by Greek and Muslim astronomers; an added refinement was introduced early in the seventeenth century by the 'Dutch Eratosthenes,' Willebrord Snell, who, instead of actually measuring his meridian arc, ascertained its length indirectly by connecting it trigonometrically with a short, accurately determined base-line [7].

The essential advance achieved by Picard lay in his pioneer use of telescopic instruments to survey his arc, and to find the difference of latitude between its terminal points. The arc selected, some 80 miles in length, lay in the plains of north-eastern France; it was connected by triangulation with a carefully measured base-line. Picard's fundamental instrument was a telescopic quadrant serving to measure to the nearest minute the angular separation of two distant landmarks or signal-fires (figure 2). To measure the zenith-distances, he employed an early form of zenith-sector. The work occupied most of 1669 and 1670, and the final result gave one degree of meridian as corresponding to about 69·104 English statute miles.

Very shortly after the foundation of the Academy, Picard and his colleagues had become

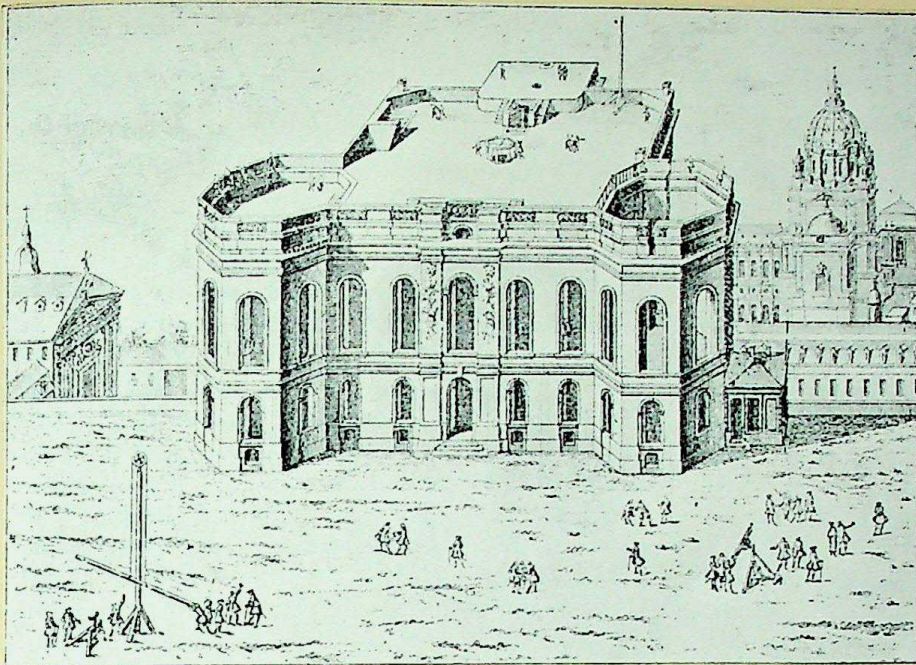


FIGURE 1 *The Royal Observatory of Paris (from P. C. Le Monnier, 'Histoire Céleste.' Paris, 1741).*

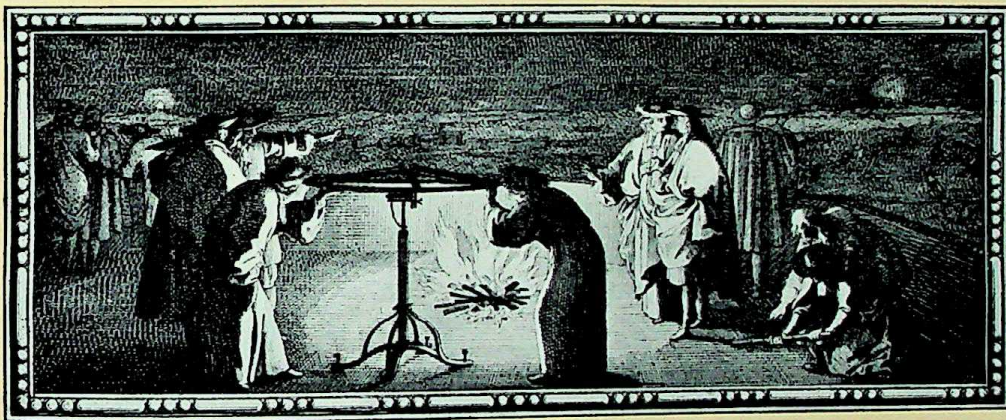


FIGURE 2 *Surveying with the telescopic quadrant (from 'Mesure de la Terre.' Paris, 1671).*

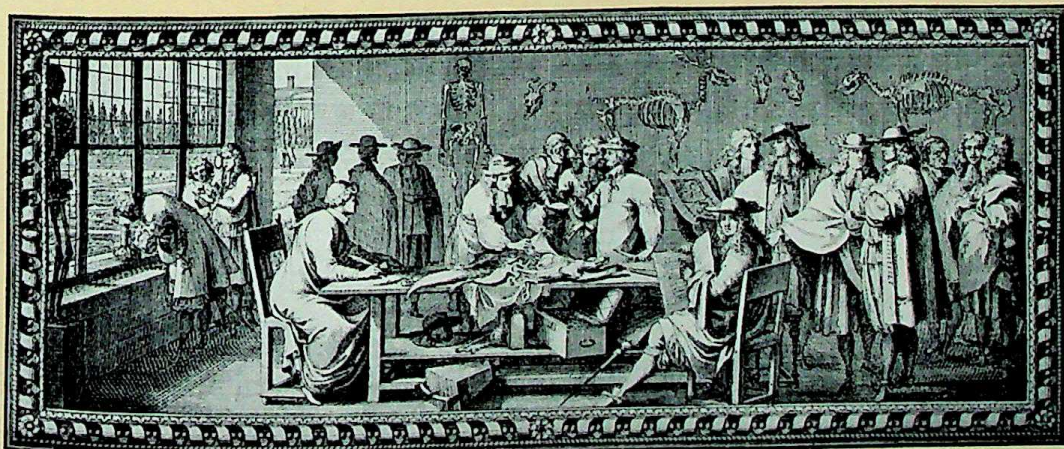


FIGURE 3 *The Académie Royale des Sciences in session (from 'Mémoires pour servir à l'histoire des animaux.' Paris, 1671).*
Illustrations by courtesy of the British Museum.

painfully aware of the inconveniences of their garden observatory, and the King had undertaken to provide them with a permanent establishment. The erection of the Paris Observatory was inaugurated with great ceremony in 1667, and the building was virtually completed by 1671 (figure 1). By the time the Observatory was in commission, the leadership of the Parisian school had largely passed from Picard, owing to circumstances connected with the solution of another fundamental problem confronting astronomers and navigators in his day—that of determining longitude.

This operation was still customarily performed by noting the local time of occurrence of some celestial event that had been predicted in the standard time of the prime meridian; the difference between the local and standard times then gave the longitude of the observer. Galileo had proposed to utilize the almost nightly eclipses of Jupiter's satellites by their primary. This idea had been taken up by the Italian astronomer Giovanni Domenico Cassini, who in 1668 had published an ephemeris of the satellites with this purpose in mind. In the same year Picard, in Paris, was acquiring practice in timing the eclipses of these objects, taking advantage of the pendulum clocks and large telescopes at his disposal. He was astonished at the accuracy of Cassini's tables, and it seems to have been at his recommendation that Colbert took the momentous step of inviting the Italian astronomer to Paris. Cassini adopted French nationality and spent the remaining forty-three years of his life at the Observatory, upon whose fortunes he and his descendants exerted a controlling influence down to the era of the French Revolution. The astronomers of the Academy had a special motive for interesting themselves in the problem of longitude. They were anxious to know the longitudes and latitudes of the principal observatories of former days, so that observations recorded at those institutions could be reduced to the meridian of Paris for comparison with the results of work in progress there. With this object in view, Picard was sent in 1671 to Tycho Brahe's old observatory of Uranienborg, on the island of Hven in the Danish Sound [8]. Accompanied by an assistant, he travelled through Holland and, after a stormy voyage to Hamburg, came to Lübeck and thence to Copenhagen. He ascended the Round Tower which King Christian IV had built as an observatory for Tycho Brahe's former assistant Longomontanus, and early in September he crossed over to Hven accompanied by the young Danish astronomer Ole Rømer. They

found the enclosure which marked the foundation of Tycho's historic observatory filled with the decaying carcasses of animals. As the severity of the climate began to affect Picard's health, he withdrew to Copenhagen and completed his task by observing from the Round Tower, which was within sight of Hven. To find the difference of longitude between Uranienborg and the Tower, an observer with telescope and clock was posted at each station to time the meridian transit of Vega, and the clocks were then compared with the aid of a fire-signal. Meanwhile, eclipses of the first satellite of Jupiter were timed at Copenhagen and Paris (where Cassini had been carrying on concerted observations), and, from a comparison of all the data, the longitude of Uranienborg relative to Paris was estimated to within about ten minutes of arc.

In discussing the results of his expedition, Picard alludes to certain annual fluctuations in the meridian altitude of the Pole Star which he had noticed over the previous ten years or so, and for which he could not account by reference either to refraction or to stellar parallax [9]. In the following century James Bradley succeeded in explaining them on his novel hypothesis of the aberration of light. The first step towards Bradley's achievement was the discovery of the finite velocity of light; this was made by Picard's young Danish assistant, Rømer, who had accompanied the French astronomer on his return to Paris, and whose famous discovery of 1676 was the fruit of his close study of the vicissitudes of Jupiter's satellites, undertaken during his association with the Academy.

In his generous commendation to the ruling powers of such men as Cassini and Rømer, whom he might so naturally have regarded as formidable rivals, Picard manifested a freedom from envy and self-seeking which stands out as the most distinctive trait of a somewhat shadowy personality.

It was Picard to whom the publication of the *Connaissance des Temps* (the forerunner of the 'Nautical Almanac') was due. The first issue, which he compiled himself, was published under royal patent in 1678-9. It gave the times of rising and setting of the Sun and Moon for Paris, Calais, Lyons, and Marseilles; information about eclipses; positions of the planets at five-day intervals, and of the Moon for every day; the equation of time; tables for stellar refraction; and other information. This publication became immediately known and used in England. The British 'Nautical Almanac' was first published for the year 1767.

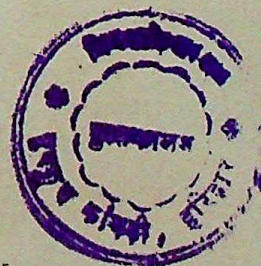
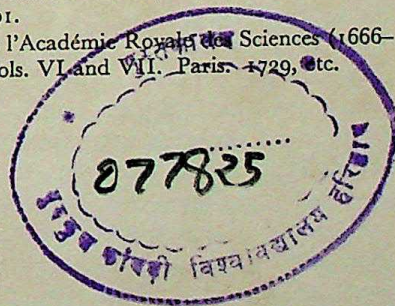
The revolution in methods of determining longitudes suggested the project of constructing an improved map of France. Beginning in 1679, Picard and the mathematician Philippe de la Hire found themselves engaged, by royal command, in geodetic operations which carried them through the length and breadth of the country. In the course of these peregrinations, Picard met with an accident and fractured one of his legs; thereafter his health failed. He was present at a royal visit to the Observatory in May, 1682, and he observed an eclipse in the following August, but on 12th October, 1682, he died [10]. No portrait of Picard appears to have come down to us, but E. C. Watson has shown that the astronomer is probably represented by the capped figure, third from the right, in Le Clerc's engraving here reproduced as figure 3 [11]. Most of Picard's observations were published by Le Monnier in 1741, and his papers, set in order by his friends, appeared with the other works of the old Academicians [12].

The deaths of Picard and Colbert, and the departures of Huygens and Rømer for their native lands, all occurring within a few years, brought to a close a brilliant chapter in the history of French astronomy. The Academy languished until the end

of the century, when it was completely reorganized; the Observatory had to wait more than a hundred years for independence and endowment. However, the schemes and inventions of Picard and his circle did not suffer neglect. His Earth-measuring enterprise was expanded after his death with the prolongation of his meridian arc across the whole of France. The resulting controversy concerning the figure of the Earth was the occasion for the celebrated geodetic expeditions to Lapland and Peru (Ecuador). Meanwhile Rømer, after his return to Copenhagen, had set up observatories on the Round Tower and elsewhere, and had equipped them with novel instruments, in the design of which the inspiration of Picard's genius is apparent; they included a transit instrument with illuminated cross-wires, a meridian circle, an equatorial, and an altazimuth. These were but the first-fruits of the vast proliferation of instruments of precision tracing their origin back to Picard's first application of the telescope to the astronomical quadrant. Well might Condorcet in after years declare that the 'useful occupations' of Jean Picard would still be found bearing interest when the lapse of ages should have effaced his very name from human memory.

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The Zoological Station at Naples

REINHARD DOHRN

For scores of biologists the world over, the *Stazione Zoologica di Napoli* has an attraction like that of the magnet for iron. A research laboratory of the first rank, it is well equipped, beautifully situated, and naturally endowed with the abundant fauna and flora characteristic of the Bay of Naples. It is something much more: in a Europe physically and mentally scourged by two world wars it is an international oasis where biologists from many countries mingle freely and discuss their investigations, their theories, and their common interests.

The international atmosphere of the *Stazione Zoologica di Napoli*, which is probably the first characteristic to impress the stranger newly arrived from abroad, is no recent development. When Anton Dohrn (1840-1909) realized his ambition to found a laboratory by the sea two ideas were uppermost in his mind. His laboratory was to be a place where the occupants would be free to concentrate their whole efforts on scientific research, untroubled by teaching and other extraneous cares, needing only to ask in order to receive whatever material was required for the prosecution of their work: and this was to be the natural birthright of scientists of all nations.

One cannot but admire the nobility of Dohrn's vision: still less can one fail to admire its realization in bricks and mortar, and in the intangible spiritual endowment which has been nourished and fostered from the early seventies of the last century to the present day.

Anton Dohrn's father was a man of wide interests, which the prosperity of his sugar-beet business in northern Germany afforded him the leisure and means to pursue. His home at Stettin everywhere showed evidence of his versatility, from the library, with his own translations of Spanish dramas and assemblage of Scottish folk-songs, to the collection of beetles justly renowned among contemporary entomologists. The young Anton's early interest in natural history, nurtured in such a home, matured into a consuming passion for zoology—the conventional sequence in the lives of so many biologists. Like many other men of his time, his imagination was fired by the work of Darwin: had he remained conventional he would have established himself in some German university, there to study evolution in the animal group of his choice. He wanted to work with marine organisms, and, following tradition, he might have stored material collected on expeditions and left it to be worked through later at his

home base. But Dohrn was unconventional: he wanted to work with living marine organisms, and this meant working at a laboratory by the sea.

Finding nothing to suit his requirements in Germany, he was drawn by the fame of Darwin and Huxley to seek advice in England, where his father was able to give him letters of introduction to fellow entomologists. Through such contacts, a Glasgow business man and amateur biologist, David Robertson, offered him hospitality at his small private laboratory on the Clyde. The stimulus of working there, together with the helpful interest of such men as Huxley, Balfour, and Ray Lankester, confirmed his intention of founding a public marine biological laboratory to meet a rapidly growing need. He later found similar interest and assistance in other European countries, after he had settled on a suitable site on the shore of the Bay of Naples. Here the fauna and flora are considerably richer in variety than are those of the north Atlantic or North Sea, and climatic conditions are such that material can be collected throughout the year.

Anton Dohrn sank his personal fortune in the venture but it was insufficient, so an aquarium open to the public was built and the daily proceeds helped to swell the fund. Of much greater significance was the establishment of 'working-tables,' whereby countries and institutions earned the right to send their scientists to work at the *Stazione Zoologica* by payment of an annual rent. This device secured a double benefit: the capital outlay and running costs of the laboratory were assured and so was its international character, since all countries making financial contribution were naturally interested in its welfare. Here, then, we have a picture of the *Stazione Zoologica* at the turn of the century: founded by a German, situated on Italian soil, and supported financially by Britain, Belgium, Germany, Italy, Russia, Austria, Hungary, America, Switzerland, and other countries.

The laboratory started as a rectangular two-storey building. Below were the show aquarium, and the *conservazione*, where daily supplies of animals and plants were received to meet the current requirements of the research workers. Above were the library, and the individual research 'tables' housed in one large laboratory. Here worked many of the great biologists of the day: Ray Lankester, Balfour, Boveri, Kowalewsky, Metchnikoff, Shipley, Hubrecht, van Beneden, Conklin, J. H. Parker, Driesch, Herbst, and T. H. Morgan, and the *corpus* of biological knowledge was much enriched by their work. Many noteworthy discoveries have been made at Naples; among them may be mentioned the respiratory enzymes of Warburg, the demonstration of neurofibrils by Apathy, and the steady elucidation—still continuing—of the fertilization and embryology of the sea urchin, pursued by generations of workers. In this last connection, it should be mentioned that the *Stazione Zoologica* is in the happy position of being able to provide mature sea urchins during most of the year. A further significant contribution by the Naples station to biological science during the last two decades of the nineteenth century lay in the field of microscopical technique. In those years, when Paul Mayer was a member of the staff, hundreds of zoologists profited from the great experience and ingenuity of this master technician, and left Naples more adept in the use of both microscope and microtome.

The *Stazione Zoologica* was not a private preserve for established biologists only: many a raw student, newly graduated, had the pleasure of making at Naples his first contribution to scientific knowledge, stimulated by the company about him, by the great profusion of research material, and, not least, by the entrancing loveliness of the Bay. For many a young student from the north of Europe the first visit to the south of Italy must have been something of a revelation. In a climate where so little effort seems necessary for the mere act of living, so much more effort can be devoted to the pursuit of science.

The fame of the *Stazione Zoologica* spread quickly, and the building was enlarged twice (in 1886 and 1904) to accommodate the increasing number of biologists wishing to avail themselves of its facilities. The extensions added a number of individual research rooms, large physiological and chemical laboratories, and rooms for other specialized purposes. The old main laboratory was meanwhile converted to house the periodicals

of the rapidly expanding library. Not least important, the building incorporated an eastward-facing balcony where, in summer, the daily mid-day meal is now served. When the *Stazione Zoologica* was first built a beach ran down from its walls direct to the sea. In 1878, however, an embankment was raised along the sea-front, and a wide carriage-way was constructed above the beach, while the immediate environs of the *Stazione* were transformed into a park. From the luncheon balcony one now looks out over an expanse of palms and flowering trees and shrubs.

When Anton Dohrn first planned the laboratory a biologist needed little apparatus in order to conduct worth-while research. Each room had a small aquarium with circulating sea-water, a bench, and a sink. These, with the addition of a microscope, a few chemicals, and glassware met most workers' needs. The *Stazione Zoologica's* great pride was its ability to furnish at all times of the year a wide range of living marine organisms collected daily by local fishermen specially trained and employed for this purpose. The Neapolitan dialect is rich and flexible, and rapidly acquired phrases to specify in other than scientific language the most strange and unusual creatures. Many of the Neapolitan fishermen have become exceedingly skilled at their work, and one in particular, Salvatore Lo Bianco, made a name for himself in the world of biology far beyond the confines of Naples.

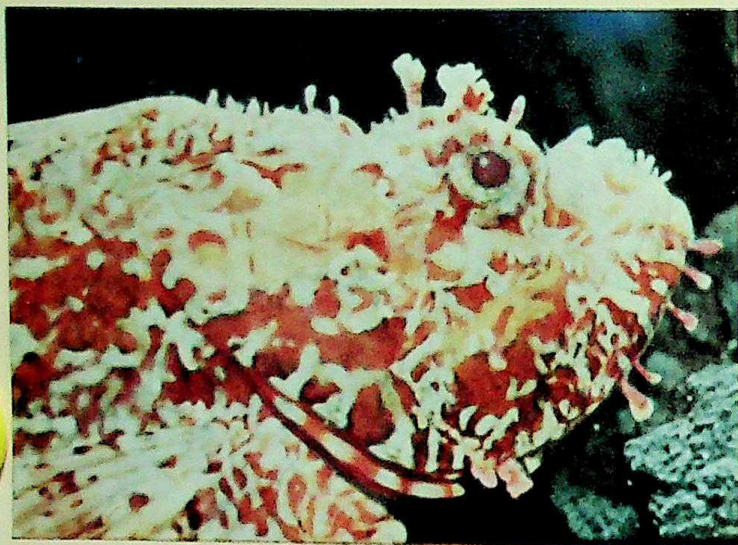
Time has not stood still within the *Stazione*. Modern biologists are much more demanding in their requirements than were their forerunners, but the laboratory has been singularly successful in keeping pace with these demands. Ideas and suggestions coming from visiting specialists from all over the world have been, and are, translated into materials and means so far as finances will allow. In recent years the extension of biochemical and biophysical techniques in biology has necessitated the installation of rooms having constant temperature and humidity, and the purchase of much special apparatus for delicate and precise measurements of various kinds. The fields of biophysics and biochemistry have profited greatly by the use of the comparative method, in which the experimenter puts the same question to a number of different kinds of organisms. The *Stazione Zoologica* has been very much to the fore in research of this kind: work on the properties of a variety of respiratory pigments, and on the nature of the electrical tissue of *Torpedo* in relation to muscle and nerve chemistry, may be



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FIGURE 1 - *Galathea strigosa*, the squat lobster.

FIGURE 2 - *Octopus macropus* walking among rocks.

FIGURE 3 - *Scorpaena scropha*, the rock-perch or scorpion-fish.

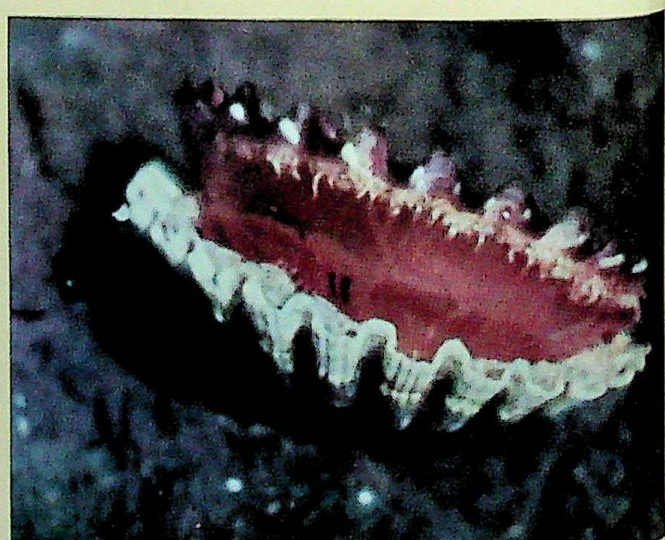
FIGURE 4 - *Pecten jacobaeus*, the scallop. Close-up of the mantle-edge, where the simple eyes may be seen as white spots.

FIGURE 5 - *Pecten jacobaeus*, a general view.

(From typical photographs taken at the Stazi



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FIGURE 6 – *Pagurus arrosor*, a hermit-crab. The gastropod shell in which the animal is living is almost covered by two sea-anemones.



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FIGURE 7 – *Loligo vulgaris*, the squid, swimming forwards.

FIGURE 8 – *Sepia officinalis*, the cuttlefish, copulating. The male is on the right and shows the intense zebra-pattern characteristic of courtship and copulation.



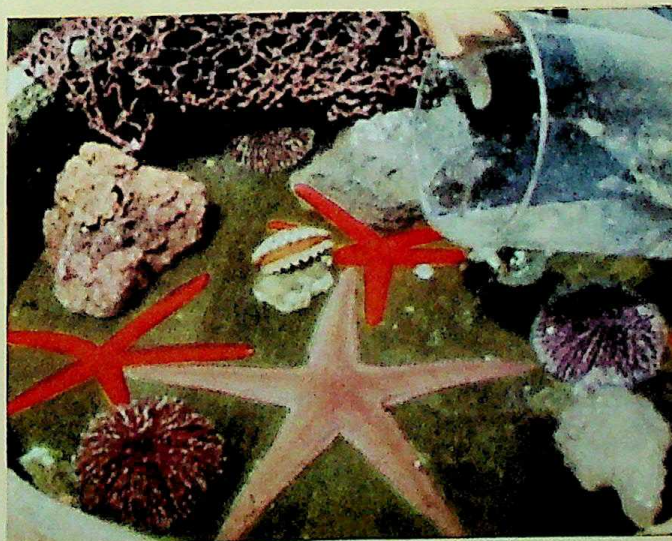
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FIGURE 9 – *Beroë forskåli*, the sea-gooseberry. Bands of swimming-plates can be seen.

FIGURE 10 – Various echinoderms, both starfish and sea-urchins.



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cited as examples. Further, great advances in biochemistry and biophysics have often followed the discovery of organisms specially suitable for particular experiments: thus one may point to the use of giant axons of squids for investigating the mode of propagation of the nerve impulse. It is somewhat incongruous that whereas marine organisms are frequently better suited for particular fundamental investigations than are the conventional laboratory animals, such as frogs and rabbits, nevertheless the great majority of well equipped biological laboratories are situated inland. To this rule the *Stazione Zoologica* is a conspicuous exception.

The task of steering the institution through two world wars has not been an easy one. In time of peace an international organization may appear strong, only to crumble overnight on the approach of war. During and immediately after the first world war there was a grave threat to the international status of the *Stazione Zoologica*; but fortunately for the world of science the original spirit in which the institution was born prevailed, and the laboratory survived as a centre of friendship between nations. During the second world war the *Stazione Zoologica* miraculously escaped significant material damage, though many bombs dropped in the surrounding park and a sea-mine exploded on the embankment hard by. There remained, however, and to some extent still remains, the problem of adequate international support. From 1939 to 1943 money was available only from Italy and Germany. Since 1944 the funds from other countries have slowly mounted; Britain gave a conspicuous lead in this respect, the Royal Society making an *ad hoc* grant of £1000 at a time when help was most urgently needed. It is unfortunate that the institution possesses no endowment that would help to tide over financial difficulties in the event of war. The post-war devaluation of the majority of European currencies has not been fully compensated by commensurate increases in 'table' rents, with the result that, of a total budget of £35,000 per annum, the Italian government has had to fill the breach to the extent of 50 per cent.



FIGURE 11 - The Stazione Zoologica, Naples.

The post-war years have seen a steady increase in the numbers of foreign scientists working at the institution, and during 1952 there were no fewer than 132 visiting workers, including 23 from Britain. The busiest period at the *Stazione* is during the spring and early summer, when the temperature is ideal for work and the majority of marine animals reach sexual maturity. At such times the endurance of the permanent staff, whose numbers have not kept pace with the increasing numbers of visitors, is stretched to the limit to keep abreast of the daily problems and requirements. The problems are not only scientific: most visitors arriving for the first time cannot speak Italian, yet have to make their wants known to the Neapolitan laboratory stewards—who, fortunately, have considerable intuitive powers. Properly to serve the *Stazione Zoologica* one must be a linguist and travel agent as well as scientist, for the permanent staff have a considerable added responsibility in advising and informing each visitor on how to get the maximum benefit and pleasure from a stay at Naples.

Luntan' a Napule nun se pò sta' in the dialect means that having visited Naples one cannot stay away. Visiting scientists bear out the truth of the words of this old folk-song, for they return year after year. Driesch came fourteen times, Apathy even more, and J. Z. Young has already been nine times. The younger visitors to the *Stazione* are no less enthusiastic than their seniors: on them, and on their influence, will fall the responsibility for upholding the internationalism which is its cherished tradition.

D. TABOR

Hardness has often been considered as a rather nebulous, not to say mysterious, property of solids. Recent investigations, however, have shown that the indentation hardness of a metal is fairly directly related to its plastic yield-stress. Moreover, extension of this work provides a very simple physical explanation of the familiar Mohs scratch-hardness scale for minerals.

I. INDENTATION HARDNESS OF METALS

In an introductory essay to his book on the hardness of metals, O'Neill [1] wisely remarked that hardness 'like the storminess of the seas is easily appreciated but not readily measured.' In general, the hardness of a solid is assessed in terms of its resistance to local deformation. We may estimate this in several ways. The most common method in metallurgical work is to press a hard indenter into the surface: a soft material suffers a large indentation, a hard material a small one. We may carry this a stage further, and calculate the mean pressure existing between the indenter and the solid when the indentation is formed; the result so obtained provides a quantitative measure of the hardness of the solid. The values are usually expressed in kg/mm^2 ; typical values are 4 for lead, 50 for annealed copper, 150 for mild steel, 900 for ball-race steel, and 1500 for tungsten carbide. It is clear that, with metals at least, indentation hardness measurements are primarily a measure of the plastic properties of the metal. Some change in the size and shape of the indentation occurs when the indenter is removed, as a result of the released elastic stresses, but the overriding effect is the plastic flow of the metal around the indenter. Consequently we may expect to find some sort of relation between the indentation hardness and the plastic properties of the metal under examination.

BASIC PLASTIC PROPERTIES OF METALS

Consider the behaviour of a cylindrical specimen of metal subjected to uniform tension along its axis. If we plot the true stress against the linear strain we obtain a straight line, the slope of which is the Young's modulus of the metal (figure 1, portion OA). Over this range the deformation is reversible, and on removing the stress no detectable residual deformation is observed. If, however, the specimen is stretched too far, the stress-strain curve deviates from the elastic curve, and on removing the stress some residual deformation

remains: plastic deformation is said to have occurred. The stress Y producing plastic deformation increases as the strain ϵ is increased. This is part of the general observation that as metals are worked or deformed they grow harder and stronger. Over a limited portion of the stress-strain curve the increase of Y with ϵ can be represented in a very crude way by a relation of the type $Y = b\epsilon^x$, where b is an empirical constant, and a similar expression holds if the metal is compressed plastically between 'frictionless' anvils. The index x is sometimes called the work-hardening index; it has a value ranging from zero for metals which do not work-harden to about 0.6 for fully annealed metals capable of undergoing very marked work-hardening.

If the tensile specimen is deformed up to D and the load is removed, the specimen recovers elastically to the point O', where OO' is the amount of permanent or plastic deformation. If this work-hardened specimen is now subjected to a renewed tensile test with the point O' as the new origin, the stress-strain curve follows the path O'DE.

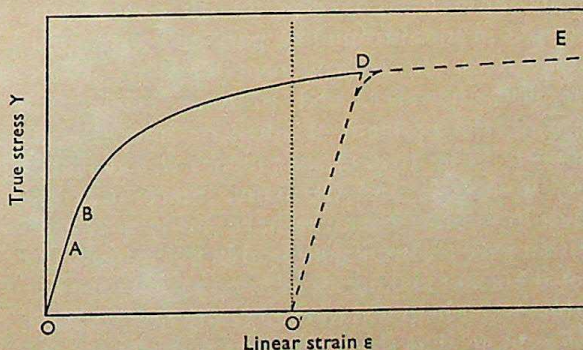


FIGURE 1—Stress-strain curve for a metal under tension. OA represents the initial elastic deformation. At B, plastic deformation begins. As deformation proceeds there is a steady increase in the yield stress. At D, if the stress is removed the stress-strain curve follows the reversible path DO', and OO' is the residual plastic extension. If the specimen is now subjected to further extension so that O' becomes the new origin, the stress-strain curve follows the path O'DE. The yield stress now shows little increase with increasing strain.

the stress-strain curve follows the curve $O'DE$, i.e. the yield-stress Y is almost constant. This means that if an indentation is made in a material in this condition any work-hardening produced by the indentation process itself will have a negligible effect on Y . We may thus expect a relation between Y and the indentation hardness.

INDENTATION OF IDEAL PLASTIC MATERIALS

A material for which Y is constant is called an ideal plastic material. The first theoretical treatment of the indentation of such a material was made over thirty years ago by Prandtl [2], and independently by Hencky [3] a few years later. Their analysis followed from the general observation that hydrostatic pressure itself plays no part in producing plastic flow of metals. A cylindrical specimen that would yield plastically under a uniaxial tensile or compressive stress Y will not flow plastically if subjected to a hydrostatic pressure, even if this is considerably greater than Y ; a superposed uniaxial stress of amount Y must still be applied if plastic flow is to occur [4]. This has led to the view that plastic flow is primarily determined either by a shear-stress criterion, or by a maximum shear-strain energy criterion. Prandtl and Hencky showed that when these criteria are applied to the problem of an indenter producing localized plastic indentation, nearly two-thirds of the mean pressure of contact is in the form of a hydrostatic pressure and only one-third remains effective in producing plastic flow. If P is the mean pressure between the indenter and the metal and Y is the yield-stress, then

$$\frac{1}{3}P \approx Y \quad \text{or} \quad P \approx 3Y.$$

VICKERS HARDNESS OF IDEAL PLASTIC MATERIALS

The most common type of indenter used in metallurgical hardness measurements—the Vickers indenter—is a square-based pyramidal diamond in which the angle between the opposite faces is 136° (figure 2a). Plasticity theory suggests that the mean yield-pressure will depend somewhat on the angle of the indenter, but the relation between P and Y will be close to that given in the above equation. This conclusion may be examined by work-hardening metals as far as convenient, until a portion of the stress-strain curve is reached where Y is substantially constant. Vickers indentations may then be made and the mean pressure P over the indentations calculated. This is given by

$$P = \frac{\text{Load}}{\text{Projected area of indentation}}.$$

TABLE I

Relation between yield-stress Y and indentation pressure P .
(Vickers Indenter)

Metal	Y (kg/mm ²)	P (kg/mm ²)	P/Y
Tellurium-lead	2.1	6.7	3.2
Aluminium ..	12.3	39.5	3.2
Copper ..	27	88	3.3
Mild steel ..	70	227	3.2

Typical results are given in table I [5]; it will be seen that for a wide range of materials $P = 3.2Y$. Since the Vickers hardness number H_v is defined as the ratio of the load to the pyramidal area of indentation, H_v is less than P by a numerical factor depending on the shape of the pyramid. For the standard Vickers indenter this factor is 0.9272. Consequently

$$H_v = 0.9272 \times 3.2Y \approx 3Y.$$

Hence the Vickers hardness number of an ideal plastic material is roughly three times its yield-stress. This astonishingly simple relation, which follows directly from the work of Prandtl and Hencky, appears to have been overlooked in hardness literature for almost thirty years. Although many other factors are involved, it remains the basic relation between the indentation hardness and the bulk properties of a metal. Further, since an ideal plastic material under tensile conditions passes its maximum nominal tensile stress T_u as soon as plastic yielding begins, Y is essentially the

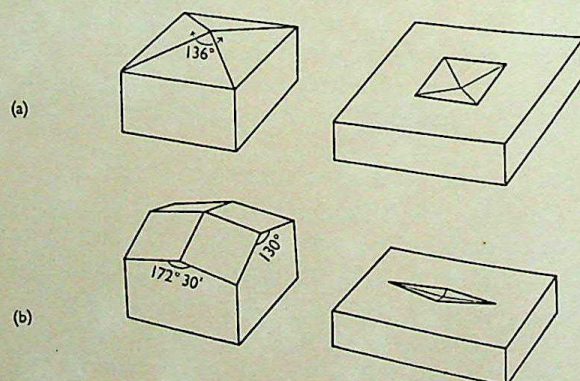


FIGURE 2—(a) Standard Vickers diamond pyramid indenter and the square-shaped indentation that it forms. (b) Standard Knoop diamond indenter and the elongated indentation that it forms. The Knoop indenter (p. 31) appears to be better suited for the indentation of brittle materials.

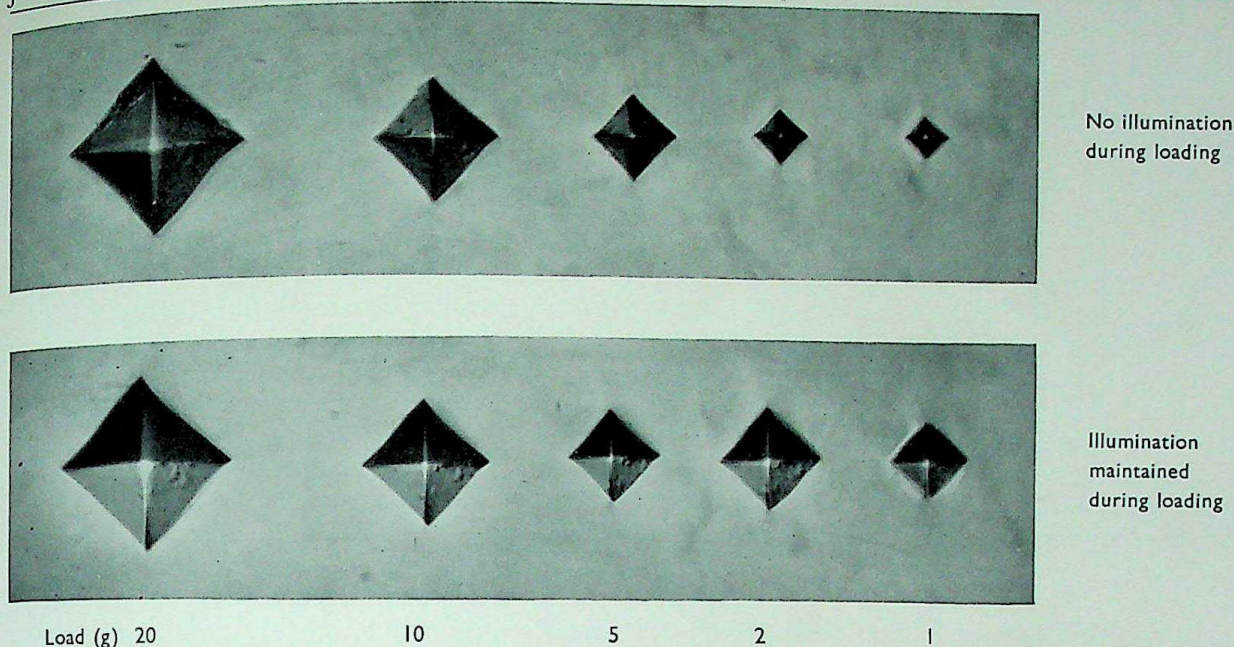


FIGURE 3 - Indentations formed by a Vickers indenter on the surface of annealed aluminium which has been electrolytically polished. When all external vibration is eliminated and the illuminating light source switched off during loading, the indentations decrease regularly in size as the load is reduced. The hardness is essentially constant. If the illumination is maintained during loading, the vibration produced by the light source makes the indentations (for loads less than 10 g) larger than they should be; the hardness appears to decrease at small loads. (From Wilson [6].)

same as T_u . Hence the hardness value gives a direct measure of the ultimate tensile strength; indeed, to a close approximation, $T_u = 0.33H_v$.

PRINCIPLE OF GEOMETRIC SIMILARITY

It is convenient, before considering the hardness of metals which work-harden, to discuss the principle of geometric similarity. If two indentations are made of the same geometric shape, then, whatever their size, the strain distribution and the stress distribution around the indentations will be geometrically similar. This arises from basic physical considerations, and is valid whether the material undergoes work-hardening or not. In its simplest terms it implies that a large indentation is essentially a magnified picture of a small indentation, the stresses and strains being the same at any geometrically similar region. Consequently the yield-pressure, which is the mean pressure acting on the indenter, will be the same whatever the size of the indentation. It follows that for a pyramidal (or conical) indenter the hardness is independent of the size of the indentation and hence of the load. This is well borne out in Vickers hardness measurements.

This principle has a direct bearing on microhardness measurements involving the use of a pyramidal indenter. It is often found that at small

loads the hardness is greater than at large loads. This is not due to a breakdown of the law of geometric similarity. It arises from the fact that the surface layers of the specimen are harder than the substrate, and that for sufficiently small loads the hardness values approach the true hardness of the surface layer, while for large loads and deep indentations the hardness approaches the bulk hardness of the substrate.

When the loads become very light it is sometimes found that the hardness appears to decrease. Recent experiments by Wilson [6] with a beam-loading type of microhardness apparatus have shown that this is due to vibration, which at very small loads makes the indentation larger than it would be if the loading were perfectly static. With the type of apparatus used by Wilson, in which the loading mechanism is supported on the stage of a standard optical microscope, it is found that, even if all extraneous vibrations are avoided, serious errors may arise from vibrations produced by the light source used to illuminate the specimen. If the light source is maintained while the indentation is made, indentations below a load of 10 g are greater in size than they should be; if the light is switched off during the actual loading operation, uniform results are obtained (figure 3). This work and other similar investigations show that

the variation of hardness with load for pyramidal indenters is due either to a genuine variation of hardness with depth or to some instrumental characteristic.

VICKERS HARDNESS AND BRINELL HARDNESS

When a pyramidal indenter is pressed into a metal, it deforms the metal plastically and work-hardens it, i.e. it raises the value of Y . The plastic strains produced will vary from point to point, and hence the yield-stress Y will also vary from point to point. We may, however, assume that there is a representative value of the yield-stress Y_r which is related to the observed Vickers hardness by the relation $H_v = cY_r$, where c again has the value of about 3. By an empirical method it is found that the indentation produces an average or representative strain ϵ_r (corresponding to Y_r) equivalent to an 8 per cent. tensile strain. Hence if on the known tensile stress-strain curve of the metal we determine the yield-stress for an additional 8 per cent. strain, the Vickers hardness value will be three times this value. Because of the principle of geometric similarity, this additional strain will be the same whatever the size of the indentation. It also turns out that the additional strain is roughly constant whatever the initial state of work-hardening of the specimen. This is shown in table II for annealed copper and steel specimens which were work-hardened by various strains ϵ_0 and had their Vickers hardness measured. The yield-stress at a strain of $(\epsilon_0 + 8)$ per cent. was determined from

their stress-strain curves and compared with the observed Vickers hardness values. The agreement between the last two columns is fairly good, and indicates that the basic assumptions are reasonably valid.

It is evident that the indentation hardness is a measure of the plastic yield-stress of the metal as augmented by the indentation process itself.

An older type of hardness measurement, due to Brinell, involves the use of a spherical indenter. Here again the indentation pressure is roughly three times the yield-stress of the metal, so that Brinell hardness numbers and Vickers hardness numbers have very nearly the same value. A fundamental difference arises, however, from the fact that indentations of various sizes formed by a given spherical indenter are not geometrically similar. A large indentation produces greater plastic strains than a small indentation, a larger increase in the effective yield-stress, and hence an appreciable rise in the observed hardness. A detailed examination [5] shows that, if d is the chordal diameter of the indentation and D the diameter of the ball, the indentation pressure P may be expressed approximately by the relation

$$P = P_0(d/D)^x,$$

where x is the work-hardening index. Thus hardness measurements with spherical indenters can provide a fairly direct measure of the ability of a metal to be work-hardened. This is an important property of a metal, for it is closely connected with its ductility.

TABLE II

Relation between yield-stress Y and Vickers hardness number, for metals which are work-hardened by the indentation process

Metal	Initial deformation ϵ_0 per cent.	$(\epsilon_0 + 8)$ per cent.	$Y(\text{kg/mm}^2)$ at strain of $(\epsilon_0 + 8)$ per cent.	cY	Observed Vickers hardness number
Mild steel	0	8	55	$c = 2.9$ 159	156
	6	14	62	176	177
	10	18	66	190	187
	13	21	67	194	193
	25	33	73	211	209
Annealed copper	0	8	15	$c = 3.0$ 45	39
	6	14	20	60	58
	12.5	20.5	23.3	70	69
	17.5	25.5	25	75	76
	25	33	26.6	80	81

II. SCRATCH-HARDNESS OF MINERALS:

THE MOHS HARDNESS SCALE

Another way of estimating hardness, originally developed by mineralogists and lapidaries as a means of identifying or assessing the physical properties of stones or minerals, is the scratch-hardness test. The form of this test which has been most firmly established for more than a century is that due to Mohs [7], who proposed ten minerals in increasing order of scratch-hardness as the units of his hardness scale. Each mineral will scratch the one on the scale below it but will not scratch the one above it. At first sight it would appear that such a scale might be so arbitrary as to have no basic physical significance. Mohs

himself was aware of this difficulty, and in selecting his standard minerals for the construction of his scale he emphasizes that 'the intervals between every two members of the scale be not so disproportionate as either to render its employment more difficult, or to hinder it altogether.' With these precautions in mind, Mohs finally proposed as his ten basic minerals: 1 talc, 2 gypsum, 3 calcite, 4 fluorite, 5 apatite, 6 orthoclase, 7 quartz, 8 topaz, 9 corundum, 10 diamond. Mohs nowhere explains his criterion of perfect equality of the intervals, but he observed that the gap between corundum and diamond is greater than it should be. Recent work shows that there is, in fact, a sound physical basis upon which equal intervals can be constructed, and that the Mohs scale follows it surprisingly well.

INDENTATION HARDNESS OF MINERALS

In discussing the scratch-hardness of minerals it might seem that we are concerned primarily with the behaviour and physical properties of relatively brittle materials. This, however, is not so. The work of Bridgman [8] and others has shown that under sufficiently high hydrostatic pressures brittle materials may be prevented from fracturing, so that any deformation which they undergo under these conditions is essentially plastic. As we saw earlier, the stresses around an indenter are equivalent to a hydrostatic pressure on which is superposed a shear-stress. With many materials, these hydrostatic pressures are sufficient to inhibit brittle fracture, and very satisfactory plastic indentations may be obtained even though some cracking may occur [9]. Further, in the scratch process itself, the conditions at the contact region are similar to those around a static indenter. Here again a detailed examination shows that, although some fragmentation may occur, the deformation is dominated by the plastic flow of the material [9]. Since, therefore, both the scratching process and the static indentation process are determined primarily by the plastic properties of the material, we may expect to find some correlation between the Mohs hardness and the indentation hardness. This correlation does in fact occur, as is shown in figure 4, the data being based on indentation hardness measurements made with the standard Vickers indenter [10, 11], and also with the Knoop type of indenter [12, 13], which appears to give somewhat less cracking of brittle materials (figure 2*b*). The general trend is clear. The indentation hardness rises monotonically with increasing steps for each increment of the Mohs scale.

THE SCRATCH-HARDNESS OF METALS

Since scratch-hardness involves, primarily, the plastic properties of minerals, its investigation is greatly simplified by using metals instead of minerals. A simple experiment along the following lines at once reveals the basic characteristic of a scratch-hardness scale [14]. By suitable heat-treatment, a strip of metal is rendered soft at one end and hard at the other, with a fairly uniform increase in indentation hardness along its length. Another metal specimen of uniform intermediate hardness is prepared with a sharp point at one end, and the point is dragged over the strip from the soft to the hard end. It is then found that, over the soft portion of the strip, the friction is high and the motion intermittent, and a fine chip or shaving is produced. The behaviour remains much the same as the point approaches the harder end, until at a critical hardness of the surface the friction suddenly drops to a low value and the surface damage becomes negligible. Scratching has ceased. Applying this experimental procedure as a general criterion of scratching, it is found that a point of indentation hardness H_p will scratch a surface of indentation hardness H_s only if $H_p \geq 1.2 H_s$. The reason for this is not clear, for it does not appear to depend very critically on the shape of the point. Assuming, however, that scratching just occurs when $H_p = 1.2 H_s$, we may construct a hardness scale in which every unit is 1.2 times as hard as the preceding one. The scratch-hardness number M is then related to the indentation hardness H by a relation of the form $H = k(1.2)^M$. Taking logarithms of both sides, we have $\log H = M \log 1.2 + k_2$, where k_2 is another constant equal to $\log k$. Thus a plot of $\log H$ against M should give a straight line of slope $\log 1.2$. In practice we may wish to avoid the chance of an overlapping of the units by increasing the ratio to something greater than 1.2, but the general characteristic would still be a linear relation between $\log H$ and M .

The results obtained by Winchell and Taylor, shown in figure 4, have been plotted in this way in figure 5, and it is seen that, if diamond be excluded, the relation $\log H = nM$ is surprisingly well obeyed. The value of n corresponds to a ratio of hardness between each Mohs unit of about 1.6. Thus the Mohs hardness scale gives scratch-hardness values which correspond to fairly well defined indentation hardnesses, each increment on the Mohs scale corresponding roughly to a 60 per cent. increase in indentation hardness.

This simple relationship is not surprising when

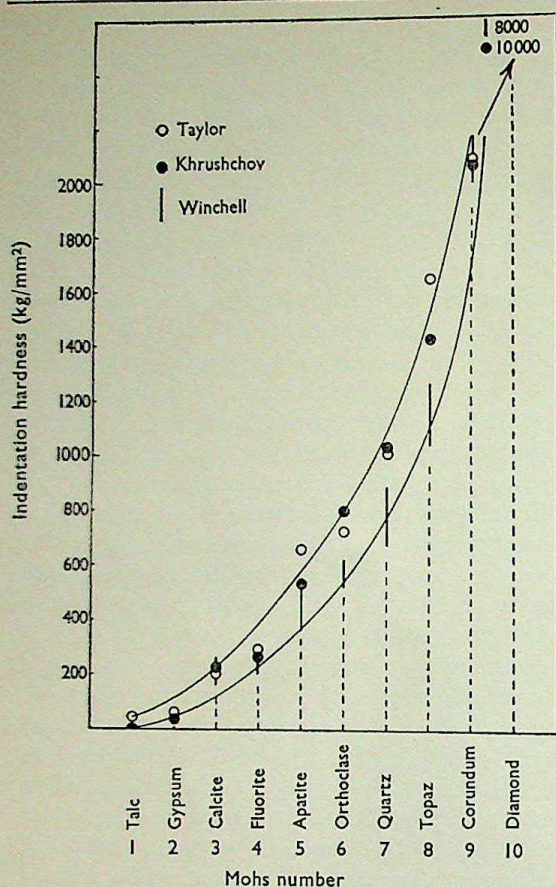


FIGURE 4 - Relation between Mohs hardness numbers and indentation hardness values. Vickers indenter: ○, results from Taylor (1949); ●, results from Khrushchov (1949). Knoop indenter: |, results from Winchell (1945) and Knoop et al. (1939).

it is realized that figure 4 is representative of many physiological processes in which the response is proportional to the logarithm of the stimulus. It is clear that Mohs did not simply choose ten

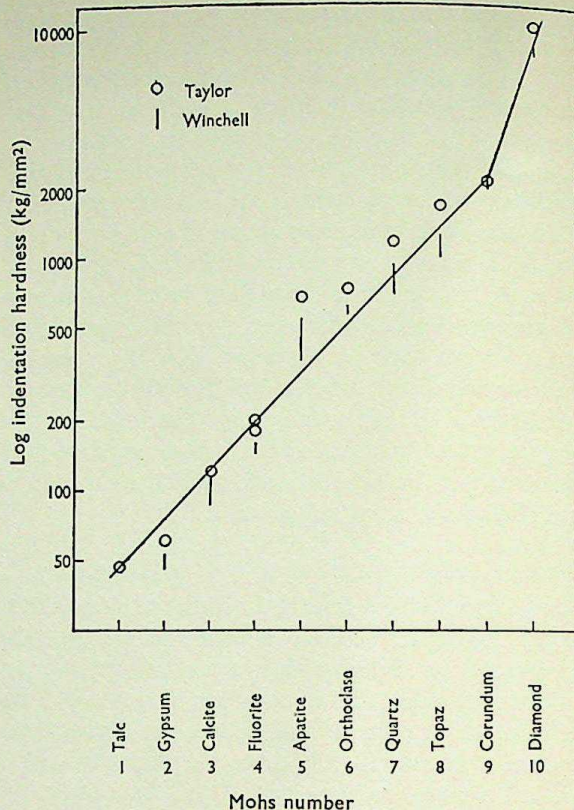


FIGURE 5 - Mohs hardness number M plotted against $\log H$, using the data of Taylor and of Winchell and Knoop et al. M is approximately proportional to $\log H$. Each Mohs interval corresponds to an increase in indentation hardness by a factor of about 1.6.

common minerals arranged in order of increasing hardness; he must have experimented with a much larger number until he had satisfied himself that he had obtained 'equality of the intervals.' His criterion was presumably a tactile one, and under these conditions the same logarithmic law apparently applies.

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Heredity in *Paramecium*

G. H. BEALE

The unicellular nature of *Paramecium* and the peculiar mechanism of its conjugation process make it an organism particularly suitable for the study of the role of cytoplasm in heredity. Experiments here described have hitherto been concerned with two systems of inheritance—the 'killer' system and the antigen system—and seem to establish that at least in *Paramecium* the cytoplasm is important in heredity, though it is too early to draw any general conclusions from this.

It is now accepted by geneticists and most other biologists that the determinants of hereditary characters, the genes, are situated in the nuclei of plant or animal cells and are arranged linearly along the chromosomes. It is, however, a fallacy to suppose that the genes have a monopoly in the control of hereditary processes, and that no other cellular constituents possess any comparable importance. Examples of cytoplasmically inherited characters have been known since the earliest days of genetics, especially in plants, but the number of such examples has admittedly been small in comparison with the gene-controlled characters.

There is obviously room for further investigation in this field, and many workers, while admitting that no cell can function for long without a nucleus, believe that materials in the cytoplasm are as indispensable as the genes for the successful development of an organism. For technical reasons, however, the role of the cytoplasm in heredity has generally been neglected in studies of the favourite subjects of geneticists, such as *Drosophila*. Consequently, in recent years some geneticists have turned their attention to other organisms more suitable for the investigation of this problem, and foremost among these is the ciliate protozoon *Paramecium aurelia*.

Individuals of *Paramecium* multiply by binary fission, whereby the daughter cells obtain nuclear constituents exactly the same as those of their parents. Samples of a population of cells derived from a single individual may easily be isolated into drops of water, and subjected to various treatments which produce more or less permanent changes. Furthermore, thanks to the discovery of the mating-type system by Sonneborn [1], matings may be made between the changed cells and those from which they were derived. Only in a unicellular organism like *Paramecium* is such a procedure possible, since in higher organisms the fertilization process involves special germ cells which are

well protected from environmental variations, and can be modified only by such drastic methods as treatment with X-rays, mustard gas, and so on.

Paramecium has yet another advantage as a choice for investigation: the sexual process involves the peculiar phenomenon of conjugation, in which two individuals undergo a reciprocal exchange of haploid nuclei with little or no exchange of cytoplasm (though exceptionally, and especially under certain known conditions, large quantities of cytoplasm may be exchanged). Consequently, after conjugation the two ex-conjugants, and all the cells derived from them by fission, contain identical nuclei, half derived from one parent and half from the other. If the parents differed cytoplasmically, however, the progeny of one ex-conjugant will be expected to contain one kind of cytoplasm, and the progeny of the other ex-conjugant the other kind of cytoplasm. The organism is therefore pre-eminently favourable for investigating the relative importance of nucleus and cytoplasm in the determination of hereditary traits.

THE 'KILLERS'

It was reported in 1939 by Sonneborn [2] that certain races of *Paramecium*, the 'killer' races, exuded into the water a poisonous substance which killed individuals of other, 'sensitive,' races. The killer character was hereditary, and was determined by a combination of genes and cytoplasm. Thus if a killer animal of stock 51 (variety 4) was crossed with a sensitive animal of stock 47 (also variety 4), those ex-conjugants which received cytoplasm from the killer parent were killers and those which received cytoplasm from the sensitive parent were sensitives; where, however, there had been visible transfer of cytoplasm during conjugation, both ex-conjugants yielded killer offspring. Sonneborn therefore postulated a cytoplasmic factor *kappa* as the hereditary unit

responsible for the development of the killer character. Further work, however, showed that nuclear genes also were involved, for if killer animals of stock 51 were mated with sensitives of stock 32, and the resulting hybrids made to pass through autogamy (a process of internal self-fertilization occurring in *P. aurelia*), it was found that some animals, though they had received cytoplasm from the killer parent, were nevertheless sensitives. Simple breeding analysis showed that a dominant Mendelian factor, called *K*, had to be present in the nucleus, in addition to *kappa* in the cytoplasm, for the development of the killer character (figure 1). If the gene *K* was not present, *kappa* disappeared from the cytoplasm. Once *kappa* was lost, it could never be formed again, even in the presence of *K*, unless at least one 'unit' of *kappa* was introduced from the cytoplasm of another killer animal.

It was therefore clear that *kappa* had a considerable degree of autonomy. Furthermore, several different kinds of *kappa*, and mutation from one to another, were found to occur [3]. These and other facts made it seem likely that *kappa* was a unit somewhat resembling a gene but situated in the cytoplasm instead of on a chromosome. The term plasmagene was therefore applied to it. This aroused much controversy. Supporters of classical genetics feared a threat to the position of the nuclear gene, which might not after all be the only indispensable unit of heredity; other workers hoped that at last it had been shown that the cytoplasm was just as important as the genes.

In 1948, however, Preer [4] succeeded in making *kappa* visible. He stained killer parametia by the Feulgen method and found that each cell contained some hundreds of Feulgen-positive particles, easily visible under the microscope, while sensitive animals contained no such particles. Furthermore, Sonneborn [5] was able, though with much difficulty, to infect parametia with *kappa* by means of a concentrated *Brei* (mash) made from ground-up killer animals.

It therefore became possible (as had earlier been suggested by Altenburg and others) that *kappa* was not so much a cytoplasmic gene as a symbiotic organism, and not an essential part of the hereditary apparatus of *Paramecium*. Those who formed this opinion were inclined to dismiss the whole matter by asserting that *kappa* was 'only' a virus. The analogy with viruses (or bacteria) is however by no means perfect, and it is probably safest to regard *kappa* as a particle which has peculiarities of its own and is not to be identified either with

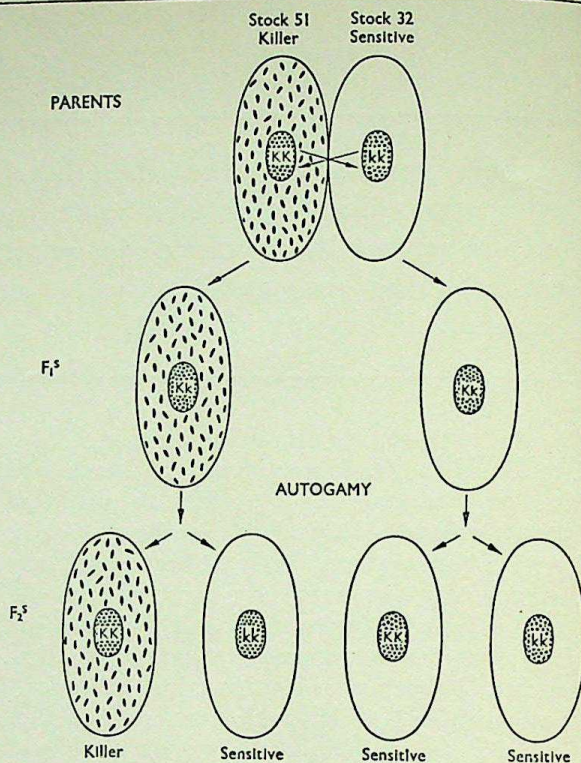


FIGURE 1 — Inheritance of killer character.

the genes, on the one hand, or with the viruses, on the other. Recent work by Chao [6] has indeed shown that the relationship between *kappa* and the gene *K* is remarkably precise, in that parametia of the genetic constitution *KK* contain twice as many *kappa* particles as parametia of the constitution *Kk*, other circumstances being the same.

It is uncertain how widespread *kappa*-like particles are in nature, apart from those occurring in various races of three out of the eight varieties of *P. aurelia*. It is well known that Feulgen-positive material is rarely found outside the chromosomes, and we may therefore be dealing with a phenomenon of only limited occurrence. Nevertheless, interesting parallels are to be found between the *kappa* particles here described and, for instance, the pro-virus particles assumed to be present in lysogenic bacteria [7].

THE ANTIGENS

It has been known for many years that if parametia are injected into rabbits, the latter produce antibodies effective in immobilizing and killing parametia of the same type as those injected. It has also long been known that a given sample of parametia may contain some individuals which are completely unaffected by an anti-serum which is highly toxic to the majority. The genetical

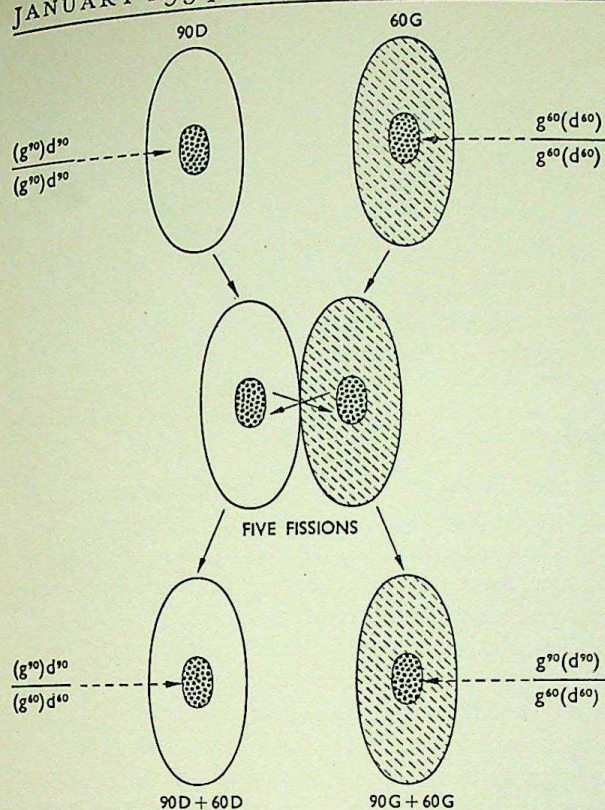


FIGURE 2 — Inheritance of antigenic types after five fissions following cross $90D \times 60G$. Genes in brackets are unexpressed.

aspect of antigen variation of this kind has been under investigation for some years by Sonneborn [8], Beale [9], and others.

The first remarkable fact to be discovered was that paramecia of a single stock, i.e. those which had all been derived by asexual reproduction from a single, homozygous individual, could change in a striking manner from one antigenic type to another. Thus type A might change to type B, or the reverse. Such types could be readily distinguished by their reaction to two different antisera, called anti-A and anti-B respectively. Further work showed that a whole series of antigenic types could be produced within a single stock. By 1950, as many as eight such types had been reported for stock 51, and there are undoubtedly more to be found. Each of these eight or more types contained exactly the same genes, but it was shown by Sonneborn that they differed in their cytoplasm.

Transformation from one antigenic type to another could be facilitated by a number of treatments, such as by varying the temperature or quantity of food or the salinity of the medium, or by treating the animals with a sub-lethal dose of homologous antiserum. Induction of an antigenic

change by the last-mentioned treatment is of special interest, in that it would appear to be an example of a hereditary change or mutation to a type more favourably adapted to the inducing environment. Such a result is of course incompatible with orthodox genetical theory. However, it must be emphasized, first, that these directed changes in *Paramecium* are cytoplasmic, and have nothing to do with gene mutations; and secondly, that treatment with weak homologous antiserum by no means always produces such changes. Individuals recovering from serum treatment are frequently of the same antigenic type as before.

As stated above, the environment had a marked influence on the antigenic type formed. Nevertheless, more than one type could be perpetuated in different animals of the same stock under identical conditions. For example, Sonneborn and Le Suer [10] showed that in stock 51 three different types—B, D, A—could be maintained indefinitely by growing the animals at 27°C with sufficient food for one fission a day. Under such conditions the diverse kinds of cytoplasm persisted for many generations, i.e. they were hereditary. Thus it appeared that variations in the antigens were controlled exclusively by cytoplasmic factors, and that nuclear genes played no part in the system at all. However, later work by Sonneborn with variety 4, and by Beale with variety 1, showed that the genes did after all control the antigenic type in an exceedingly precise manner.

In each stock of variety 1, three antigenic types were commonly found: S at low temperatures, G at medium temperatures, and D at high temperatures. Each stock formed its own characteristic variants of these three types. For example, stock 90 formed the type 90G, while stock 60 formed the type 60G, which was serologically quite distinct from 90G. Genetic analysis showed that these two variants of the G type were determined by a pair of allelic genes, called g^{90} and g^{60} respectively. Furthermore, the high temperature (or D) types of these two stocks, 90D and 60D, were also serologically distinct, and also controlled by a pair of alleles, d^{90} and d^{60} . The d alleles were, moreover, at a different place on the chromosomes from the g alleles.

Antigenic specificity therefore depended upon which allele at a given locus the paramecium contained. For each antigenic type—D, G, S, etc.—a corresponding series of multiple alleles at three loci— d , g , s , etc.—was demonstrated. Every individual contained a particular allele at each of these three (or more) genetic loci.

In spite of containing genes at these several loci at one and the same time, however, an animal of a given stock showed only a single type of antigen (except in heterozygotes made by crossing animals of two different stocks, when two antigens were commonly formed in the same animal at the same time). In general, a paramecium contained antigens of type G, or of type D, but not of both types at the same time. Hence, though genes at all three loci (*d*, *g*, *s*) were present, only one of the three was expressed, that is, had any effect on the phenotype. Which one of the three was thus expressed depended upon the cytoplasm. This was clearly shown by making crosses of the type $90D \times 60G$, i.e. between animals differing both genically and cytoplasmically. In figure 2 the results of such a cross are represented diagrammatically. Parenthetically, it must be noted that since changes of environment readily cause the cytoplasm to change from one state to another, the situation shown in figure 2 is not final. By changing the temperature, paramecia descended from either of the conjugants may be made eventually to form antigens of either the D, or the G, or even the S, type.

To sum up this complex situation, we can say that each paramecium of each stock contains at least three (and probably many more) genes, of which each stock has its characteristic alleles conferring a specificity on the antigens. Each animal also contains cytoplasm of a particular kind, but the cytoplasm (unlike the genes) can be easily changed, reversibly, by various environmental treatments. Finally the kind of cytoplasm determines which of the three or more genes present in the nucleus are called into action (figure 3).

CONCLUSION

It is tempting to draw conclusions of a general nature from the two systems of inheritance here described—the killer system and the antigen

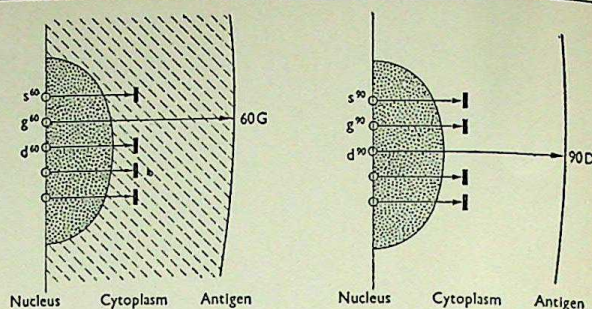


FIGURE 3—Diagrammatic representation of interaction between genes and cytoplasm leading to the formation of antigenic types 60G and 90D. Cross-hatched cytoplasm indicates 'G state'; unshaded cytoplasm indicates 'D state.'

system. Without doubt, both systems demonstrate the importance of both nucleus and cytoplasm in the determination of the hereditary characters. Furthermore, both systems, but especially the antigen one, can serve as models for cellular differentiation in multicellular organisms. Geneticists have for long been challenged by the fact that the cells of an animal or plant, though all (or nearly all) contain the same sets of genes, are extremely diverse. It has been usual to assume tentatively that the differences between the various cells of a single organism are cytoplasmic, but there was very little evidence for or against this view.

The two *Paramecium* models enable us to be somewhat more precise. On the basis of the antigen model we may assume that every cell of a multicellular organism contains many genes, of which only a small proportion influences the course of events in that cell. This small proportion is selected by the state of the cytoplasm in that cell. In other cells the state of the cytoplasm may be quite different, and completely different genes are called into action. The state of the cytoplasm is, partly at least, controlled by the environment. Thus through a complex interaction of genic, cytoplasmic, and environmental factors the various cells develop in different directions.

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Irradiation colours in minerals

KARL PRZIBRAM

Coloured modifications of normally colourless crystals, such as those of rock-salt and fluor-spar, are occasionally found in nature. The coloration appears to be conditioned by the presence of irregularities in the crystal lattice. Similar effects may be produced by exposing the crystals to radiation, and there is a good deal of evidence, both qualitative and quantitative, that this is also the process by which the minerals become coloured naturally.

The story of the geological past of the Earth is told by the rocks that constitute its crust. One aspect of this story that we are gradually coming to understand is revealed by the colours displayed by certain minerals. It has long been assumed that some of the coloured minerals, such as blue rock-salt [1] and multicoloured fluorspars [2], owe their colour to radioactive effects. This idea led to the investigation of the effect of radioactive radiations on colourless crystals.

If colourless rock-salt is exposed to radium rays it becomes yellow (figure 1(a)), but the coloration is unstable, and disappears quickly if the sample is heated to temperatures between 200 and 300° C. If the initial dose of irradiation is sufficiently strong, the yellow changes to a bluish violet (figure 1(b)) when the yellow sample is carefully heated to approximately 200° C. A similar change to a greyish colour is observed if a yellow sample is kept in the dark for long periods, or in a shorter time if it is kept in daylight (figure 1(c)).

The formation of these colours was formerly explained by assuming the absorption of a radiation quantum by a chlorine ion of the rock-salt, resulting in the loss of one electron to a sodium ion, which thus became a neutral sodium atom. This process would account for the absorption of light and consequent colour-formation. The advent of quantum mechanics, and the realization that a crystal lattice always contains gaps, led to a new interpretation [3]. According to this, the colour-centre (F-centre), which in the case of rock-salt produces the yellow coloration, is an electron held in an anion vacancy, i.e. a lattice site where a chlorine ion is missing.

The belief that coloration is caused by a permanent disturbance in the crystal lattice is confirmed by the investigation of compressed rock-salt. A radiation dose which causes yellow tinting in non-compressed salt renders the compressed salt nearly black (figure 1(d)) [4]. There is, however, an opti-

mal limit to which this disturbance can proceed, and at very high pressures the tendency to colour-change decreases. The blackening is due not only to a darkening of the yellow colour, but to increased absorption in the yellow and red regions, which, by itself, would produce violet and blue tints similar to those produced in the non-compressed yellow salt by heating. In fact, if the yellow-producing F-centres are destroyed by illumination, the dark colour of the compressed salt changes to blue (figure 2(a)). If such a blue-coloured sample is kept for fairly long periods, areas of a lighter colour will sometimes appear and gradually spread (figure 2(a)). It has been shown by various methods that this is due to an adjustment of the disturbance in the lattice, i.e. a recrystallization, and this observation provided an excellent method for the study of the recrystallization of compressed rock-salt [5].

On the basis of Siedentopf's classical investigations with the ultramicroscope, the blue colour of rock-salt was attributed to the presence of colloidal sodium particles. It has now been established beyond doubt that some of the blue and violet tints of rock-salt are not of this ultramicroscopic nature, but are caused by electrons situated at centres of stronger disturbance in the lattice (M- and R-centres) [6].

Before one can be certain that the natural colour of a mineral is due to radioactive effects, the following points have to be confirmed:

1. Gentle heating destroys the colour at temperatures of 200–300° C.
2. The disappearance of the colour is (very frequently) accompanied by thermoluminescence, the energy stored during irradiation being partly emitted as light energy.
3. The colour in the natural state agrees with the colour obtained by irradiation of the colourless mineral.

The further confirmation has sometimes been demanded that the coloration should be obtained under the same conditions as those prevailing in nature. This seems a rather unrealistic stipulation, especially when one considers the long periods of time during which the natural process works. The fact that in the laboratory the blue colour of rock-salt can be produced only by heating or illumination, whereas in the salt-deposits it has been formed in the dark and at ordinary temperatures, cannot be used to contest the radioactive origin of the colour. It seems quite possible that sufficiently long preservation in the dark at room-temperature might result in the destruction of the F-centres, with a consequent change of the grey colour into blue. The blue-producing centres are more stable than those producing yellow, and, under natural conditions, the low-intensity radiation acting in the Earth's crust will preferentially produce the more stable centres.

One of the arguments against the interpretation of rock-salt tints as irradiation colours was the absence of the primary yellow colour in nature. The discovery of yellow rock-salt at Hall in the Tyrol by Schauburger [7] has finally dispelled this objection. This salt shows the same behaviour as the yellow salt produced by irradiation; moreover, its absorption maximum is situated at the same wavelength of $460 \mu\mu$. The less frequent occurrence of the yellow salt, which has since been discovered in other places, is in agreement with its lower stability. The third rule in the above list is today expressed more strictly by the requirement that the absorption maxima in both salts must be situated at the same wavelength, as was confirmed for yellow rock-salt.

The three rules are also fulfilled for violet and for blue rock-salt. These lose their colour when moderately heated, and thermoluminescence can be observed. On the evidence of recent investigations [8], the violet colour in rock-salt is usually not caused by colloidal particles. This natural violet salt, like the violet salt obtained by irradiation and heating, shows an absorption maximum at $580 \mu\mu$. In the blue salt whose colour is of colloidal origin, absorption maxima vary with particle-size between 630 and $680 \mu\mu$. The same maxima are obtained with the blue salt prepared by heating in sodium vapour. The colloidal blue colour can also be obtained by concentrated irradiation with cathode rays at high temperature [9], though this is a more difficult method. Its occurrence in nature may be due to impurities promoting colloid formation; the long time-periods

involved in natural processes may also play their part.

The question now arises whether the small quantities of radioactive substances existing in nature are sufficiently strong to produce mineral colours. This problem was first investigated in the case of rock-salt and fluorspar [10], and the results obtained so far seem confirmatory. Rock-salt contains uranium and radium, some β -radiating potassium, and a certain amount of helium the origin of which has been explained by Hahn [11] as follows. During the Tertiary period, salt deposits were recrystallized at great depths from strongly radioactive water containing radon. The lead and its radioactive isotope RaD which this water carried were precipitated with the rock-salt and especially with the sylvine (KCl). The RaD was transformed into α -radiating polonium which, together with its parent substance RaD, has long since decayed. The α -particles which it emitted were, however, preserved in the salt as helium atoms. The calculation of the energy changes involved in this process has been published by the author elsewhere [10]. The yellow and violet tints of the mineral could have been produced by either of these sources of radiation; the blue colour, however, cannot be due to the uranium-radium content of the mineral.

On the whole, we feel inclined to accept Hahn's hypothesis. We further assume that the special sensitiveness to radiation shown by the coloured rock-salt must have been caused by impurities and other disturbances, which would explain why not all specimens of rock-salt are coloured in spite of the fact that the content of radioactive substances does not notably differ in coloured and in colourless rock-salt. With regard to fluorspars, coloration is sufficiently explained by the uranium-radium content.

Figures 2(b) and 2(c) show two samples of blue rock-salt from Stassfurt. In the former, the blue salt marks the area of contact between colourless rock-salt and sylvine; the association of blue rock-salt with sylvine is a fairly frequent occurrence, and is probably related to the secondary recrystallization process. Figure 2(c) shows a blue-black rock-salt crystal surrounded by a lighter-coloured salt of more recent origin. The jagged cleavage face of the dark blue salt indicates plastic deformation, which favours colour-formation.

The violet rock-salt found in the Grimberg shaft at Heringen in the Werra region is of special interest (figures 3(a) and (b)). Here, coloration appears in stripes parallel to the cube faces, and

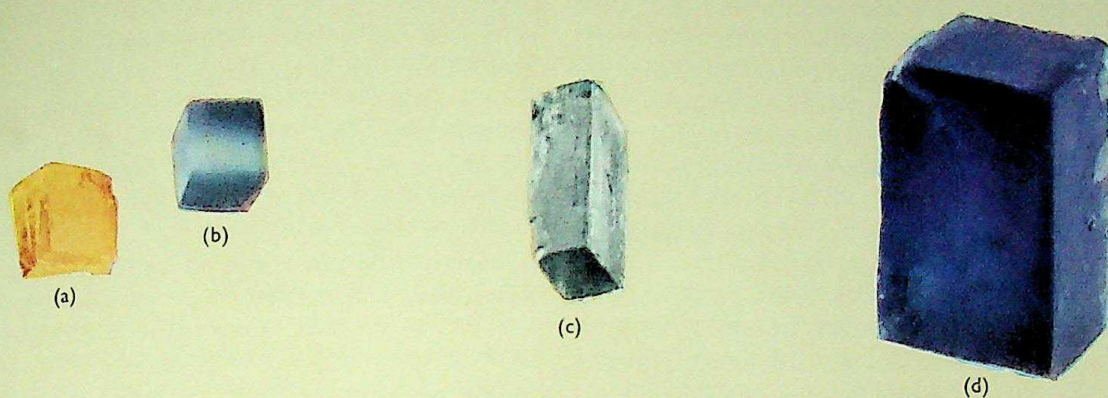


FIGURE 1 — Specimens of rock-salt coloured by radium rays. (a) Recently coloured; (b) coloured yellow originally but turned blue by heating; (c) coloured yellow originally but turned grey by ageing; (d) compressed crystal originally dark brown but turned dark blue by exposure to light. ($\times 1.5$)

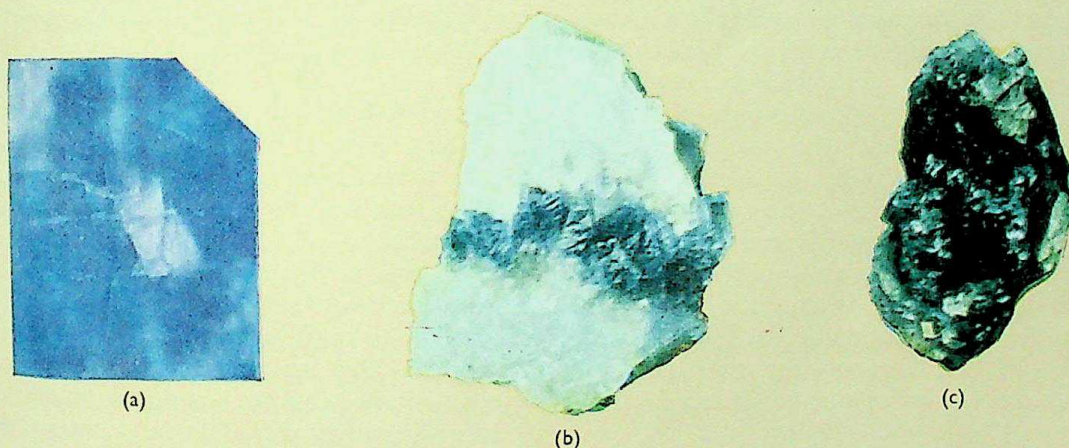


FIGURE 2 — (a) Artificially coloured compressed rock-salt, partly recrystallized; (b) composite crystal of rock-salt and sylvine (Stassfurt) with blue zone marking the region of contact; (c) varying depth of colour in blue rock-salt from Stassfurt. ((a) $\times 1.5$; (b) and (c) $\times 0.2$)

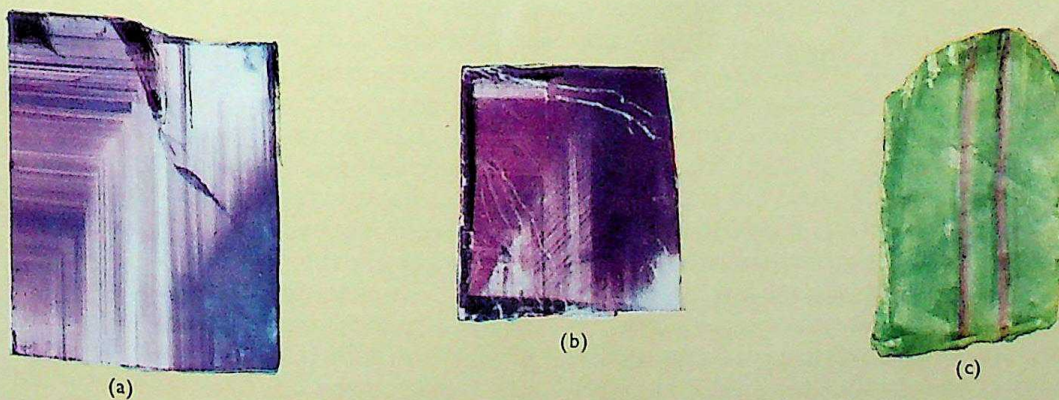


FIGURE 3 — (a) Natural blue and violet rock-salt from the Grimberg mine, Heringen; (b) violet rock-salt from the same mine, the deeper coloration marking the parts which have grown most rapidly and the darker lines the rhombododecahedral glide-planes; (c) fluorspar from Pe-shan, China. ((a) $\times 1.5$; (b) and (c) $\times 0.5$)

thus clearly indicates the way in which the crystal has grown [12]. If crystal growth had taken place at the same rate in the direction of both axes, the diagonal connecting the corners of the coloured growth-areas would have been inclined at an angle of 45° to the cube faces. As this is not so, growth must have taken place at an increased rate in the direction of the axis which makes the smaller angle with the diagonal. It further appears that the direction of growth sometimes undergoes sudden changes, for unknown reasons, and in this connection an interesting relation can be established: the pyramid formed by more rapid growth is usually darker and of a more bluish tint than that formed at the smaller rate. This indicates that increased growth-rates produce greater lattice disturbances, and therefore greater readiness for colour-formation. The same growth-areas can be observed in a rock-salt crystal coloured blue as a result of irradiation and suitable heating, and thus the growth of colourless crystals could also be investigated. By this method it was possible to observe that, in long prismatic rock-salt crystals from Wieliczka, sideways growth occasionally ceased completely and only the base moved forward. No satisfactory explanation of this singular behaviour has so far been advanced.

The dark stripes frequently observed in blue rock-salt at angles of 45° to the cube faces are the traces of the rhombododecahedral glide-planes of the rock-salt. These are more strongly disturbed, and consequently more deeply coloured (figure 3(b)).

Fluorspar shows an even greater variety of irradiation colours than rock-salt. It was the first mineral in which a colour similar to the natural coloration was artificially produced in a colourless sample. In 1830 Pearsall [13], one of Faraday's assistants at the Royal Institution, succeeded in producing pink or bluish tints in colourless fluorspar by means of the spark of a Leyden jar. The effect was probably due to the action of short-wave ultra-violet radiation. Pearsall expressed the opinion that natural coloration might be due to electrical effects, and this idea, put forward so long before the discovery of radioactivity, seems amazingly near to the modern interpretation which attributes the irradiation colours occurring in nature to the influence of corpuscular radiations (β - and α -rays).

The rules of behaviour mentioned earlier are usually fulfilled by fluorspars: they easily lose their colour and show a brilliant thermoluminescence (as has long been known), and the irra-

diation colours agree with the natural coloration.

Comparison of the absorption spectra of 20 different fluorspars, partly in the natural state, partly after irradiation [14], resulted in the determination of maxima at some of the following wavelengths: 335, 360, 370, 385, 400, 410, 430, 450, 470, 500, 525, 550, 580, 600, 625, and 640 μ . The author and his collaborators [15] succeeded in tracing the well known blue fluorescence of fluorspar to the presence of bivalent europium, and a red fluorescence band to bivalent samarium. The author was of the opinion that the bivalent rare-earth ions would also influence the absorption power of the fluorspars, and that they might be responsible for the maxima at 360 to 385 μ as well as at 430, 450, and 470 μ . This was partly confirmed by more recent observations. Freed and Katcoff [16] discovered an absorption maximum for Eu^{++} in SrCl_2 at 389 μ ; Butement [17] found maxima for Sm^{++} in SrCl_2 at 356, 377, 412, and 480 μ , and in NaCl at 357, 378, 412, and 470 μ . On the basis of these results, the fluorspar maxima at 385 μ might be due to Eu^{++} , and those at 360, 370, 410, and 470 μ to Sm^{++} . On the other hand, Smakula [18] found absorption maxima at 335, 400, and 580 μ in very pure synthetic CaF_2 after X-ray irradiation. These may be attributed to the colour-centres of the basic substance. As shown above, the same maxima are found in the absorption spectra of natural fluorspars. The maxima at 430, 450, 500, 525, 550, and 600 μ and beyond are still unexplained.

Long-wave maxima might occasionally be caused by colloidal coloration. However, the deep blue colour appearing in many fluorspars after irradiation cannot be of colloidal origin, as such specimens never show the Tyndall effect. It is likely that the final spectrum of the CaF_2 centres will prove even more complex, and the long-wave maxima will probably prove to be due to centres of stronger disturbance. It is also possible that other heavy metal ions are involved. Another point which has not been fully explained is the fact that, in different types of fluorspars, one or the other maximum is more strongly apparent. This causes the varying colours and may be partly attributed to the distribution of the rare earths, traces of which are contained in all fluorspars. Their distribution is rather irregular, even within one single crystal. It has been established that crystals or crystal layers containing a relatively high percentage of samarium will quickly acquire a deep blue coloration when irradiated. Samarium thus causes increased sensitiveness, as it is

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transformed by irradiation into its unstable bivalent form; this easily loses its surplus electron, which then serves to form a colour-centre. Earlier, Steinmetz [19] had noticed the increased sensitivity caused in fluor spar by sulphide inclusions.

Figure 3(c) shows a fluor spar from Pe-shan, China. The uneven colour distribution is clearly apparent, showing violet stripes on a green background. The fact that the green areas display a stronger bluish fluorescence than the violet stripes indicates their higher content of bivalent europium; it was possible to show that the difference is not due to an unequal absorption of the light.

Fluor spar provides another example of the principle of natural formation of the most stable. The pure blue colour frequently obtained by irradiation is very rarely found in nature; it gradually changes into the more stable violet tint which is so often observed in natural samples of fluor spar. There is also evidence for the already men-

tioned relation between colour formation and lattice disturbance: when green fluor spar is compressed its colour changes to violet, a phenomenon which might be called piezochromy [20].

So far, investigations have been concerned mainly with rock-salt and fluor spar, but it seems fairly certain that a number of other minerals owe their colours to radioactive effects. We may mention smoky quartz and amethyst, as well as mica. For mica, the ability to undergo colour-change by irradiation is confirmed by the occurrence of the pleochroic halos produced by the α -rays of radioactive inclusions. Much work has still to be done in this field.

The minerals shown in the illustrations belong to the collection of the Institute of Radium Research of the Austrian Academy of Science. The fluor spar shown in figure 3(c) was presented by Professor Iimori, of Tokio. The reader is also referred to the author's work *Verfärbung und Lumineszenz*. Springer, Vienna. 1953.

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The chelicerae of spiders

W. S. BRISTOWE

The chelicerae or jaws of spiders are equipped with poison-glands, and legends about their bites have been widespread since the earliest times. The chelicerae have an interest far beyond that of their sinister reputation, or of their ability in a few species to do serious harm to man. Their evolution, the multiple purposes for which they are used, and the structural changes they have undergone that suit them for these purposes, all repay thought and inquiry.

The class Arachnida comprises a number of orders, including the *Araneae* (spiders), scorpions, palpi-grades, phalangids (harvest-men), pseudoscorpions, solifugids, ricinuleids, acarines (mites), uropygids, amblypygids, and several extinct orders. Most of these orders were already in existence in the Carboniferous period, and we have little clear evidence as to their earlier ancestry or relationships.

Nearly all the extinct and surviving orders have chelate or pincer-like appendages on the head, called chelicerae, but those of spiders are of different design from those of the rest. In spiders, each chelicera is composed of two segments. The basal segment is thick and hard. It contains all or part of the poison gland and has limited mobility, lateral or up and down. Attached to the apical end is the fang; this is like a curved needle or a sharp thorn, near the tip of which is a tiny aperture through which the poison is extruded. When in repose the fang lies bent back along the lower or inner surface of the basal segment, often in a groove bordered by teeth.

Chelicerae of similar design are found in the extinct order *Trigonotarbi* (formerly part of the *Anthrocomarti*), and in living uropygids and amblypygids (both formerly in the order *Pedipalpi*) [12]. Although spiders and *Trigonotarbi* go back to the Devonian [6], and some of the pedipalps to the Carboniferous, it seems certain that this type of chelicera arose from the chelate or pincer form. It is not difficult to see how this development occurred (figure 1). The large tooth on the basal segment of a chelicera of the *Pholcidae* and *Scytodidae* groups of spiders is in my opinion homologous with the immovable finger of a chela. Since some arachnologists are likely to argue that the chelate appearance is accidental rather than a survival, it may be remarked that the sexual organs of *Scytodidae* and of some *Pholcidae* are not much different from those which spiders are thought to

have had early in their evolutionary history, while the epigastric plates which some species of both families possess may well be surviving relics of segmental plates. Furthermore, reference will be made in section 10 (below) to an unusual use to which pholcid chelicerae are put, a use which may have been customary amongst their earliest ancestors.

The best way of classifying spiders is into two sub-orders, the *Mygalomorphae* and the *Araneomorphae* (*Arachnomorphae*). Some authorities also recognize as distinct sub-orders the *Liphistiomorphae* and the *Hypochilomorphae*, but all agree that the former are linked in relationship to the *Mygalomorphae*, and the latter to the *Araneomorphae*. If, for our purpose, we recognize just two subdivisions of the order, we find that one constant characteristic by which they can be distinguished clearly and easily is the design of the chelicerae. In what may be called the mygalomorph type, the basal segments are directed forwards while the fangs strike downwards in a roughly vertical direction. In the araneomorph type, the basal segment usually slopes downwards, often vertically from the carapace, while the fangs move laterally, inwards towards one another and outwards (figure 2).

Both types arose very early in spider history, certainly by Carboniferous times, so that it is difficult to be sure which came first. The orientation of the chelate chelicerae of other orders provides no clue. It may be noted, however, that the Devonian *Trigonotarbi*, and the uropygids and amblypygids, all have the mygalomorph type. It is probable that the four orders shared a common ancestor, in which spider-like chelicerae of the mygalomorph type arose in or before the Devonian period. Later, during the Carboniferous period, when insects began to develop wings, the araneomorph type arose by some torsion of the basal segment, following a departure from a ground-living habit and the evolution of silk snares where

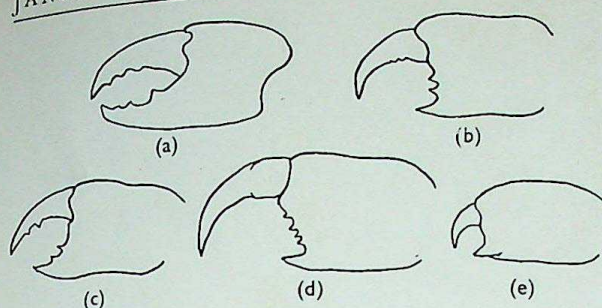


FIGURE 1 - Chelicerae of (a) the scorpions, (b) uropygids, (c) amblypygids, (d) the extinct *Trigonotarbi*, and (e) a pholcid spider.

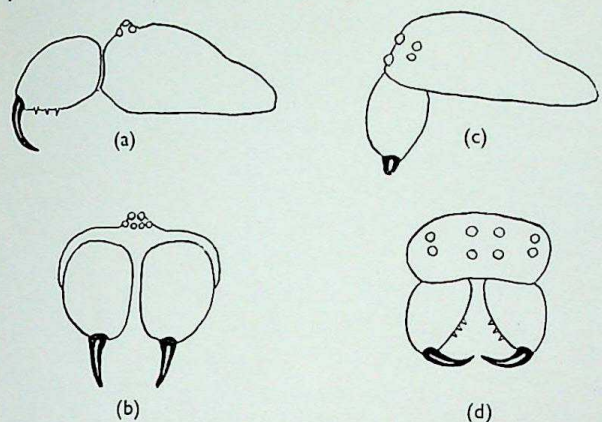


FIGURE 2 - (a) and (b) respectively show the orientation of the chelicerae of the mygalomorph spiders from the side and from the front. (c) and (d) show the orientation in the araneomorph spiders.

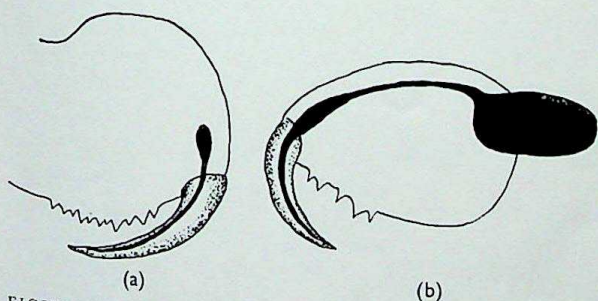


FIGURE 3 - The poison glands, shown in black, of (a) a primitive liphistiid and (b) a typical araneomorph spider.

this design would be more effective for seizing prey. The striking and piercing powers of mygalomorph fangs are greater when the victim is on solid ground than when spider and victim are suspended on elastic threads.

Although the cheliceral design of the uropygids and amblypygids is similar to that of spiders in external appearance, only the spiders possess poison glands. Our most primitive living spiders belong to the family *Liphistiidae*, whose outward appearance closely resembles that of certain Carboniferous fossil spiders. In the genus *Heptathela*

there may be no poison glands, and in the genus *Liphistius* they are very small (figure 3) [2, Millot].

The use of chelicerae as weapons of attack and defence is so well known that attention will be restricted to a few features which have been overlooked, or which have received scant attention, before passing on to a brief review of the other interesting uses to which chelicerae are put.

1. SPECIALIZED CAPTURE OF PREY

Observations on five species of *Scytodes* in Malaya and Britain [1] have confirmed the discovery [9, 10] that these spiders squirt gum at insects from a distance of a quarter to half an inch. Under a microscope it is seen that the gum pattern is that of a double series of almost parallel threads which enmesh the insect as if a net had been thrown over it. Although the operation is completed in one jerk, so far as the eye can see, it is evident that the chelicerae are in a state of rapid oscillation at the moment the gum is ejaculated from the fang-tips. Large gum-producing glands are necessary and thus additional space in the cephalothorax is needed, as in the domed cephalothorax so characteristic of *Scytodes* (figure 5).

The dorsal armour of woodlice (*Oniscoidea*) serves as a protection against the bites of most hunting spiders. Furthermore their glandular secretions make them unpalatable to many spiders [3]. Some species of woodlice, however, form a substantial proportion of the diet of the British spider *Dysdera crocata*, a slow-moving nocturnal hunter that lives under stones. Arthropods more active than woodlice can often elude a *Dysdera*, which thus may have been forced to rely largely on woodlice for its diet. Its chelicerae are specially well suited for dealing with woodlice. They are exceptionally large and powerful, and by tilting the cephalothorax sideways one fang is intruded beneath the woodlouse and the other above it. While one fang easily penetrates the soft ventral surface, the other is pressed through the dorsal armour (figure 6).

2. MACERATION OF PREY

The teeth with which the basal segment is armed may serve as some protection for the fang when in repose, but I cannot recall any precise reference to the main purpose they serve. This is to aid in the maceration of soft-bodied prey, so as to facilitate the release of body-juices for the spider to suck. A contraction of the muscles that operate the fangs causes the fangs to press the insect's body against the teeth—to exert a

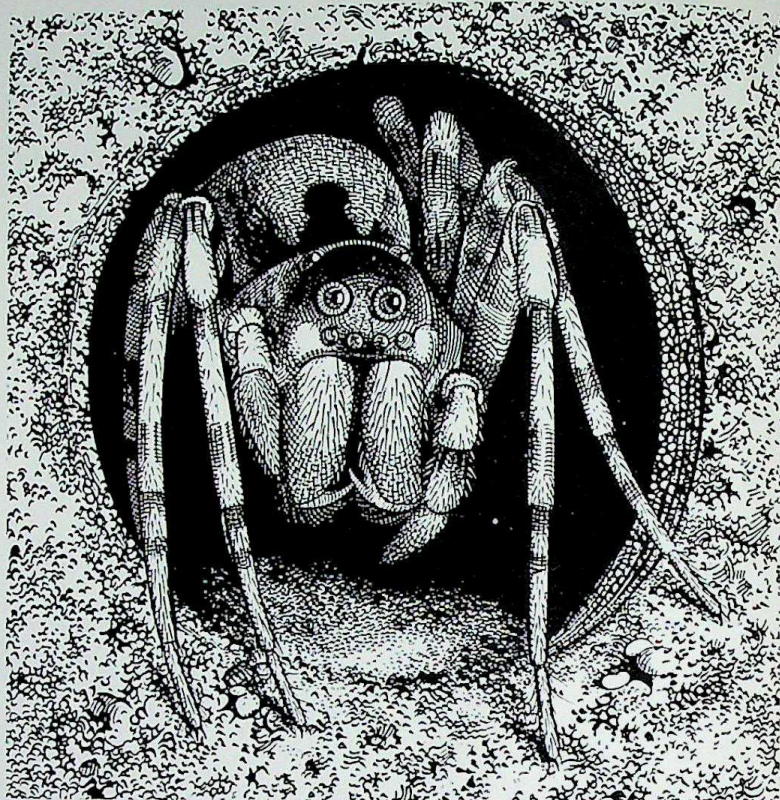
squeeze similar to that of the ancestral pincer. The sharp teeth penetrate the insect's body-wall and help to reduce it to a pulpy pellet. A serrula or series of small teeth on the border of the maxilla also contributes to this process.

3. DISSECTION OF PREY

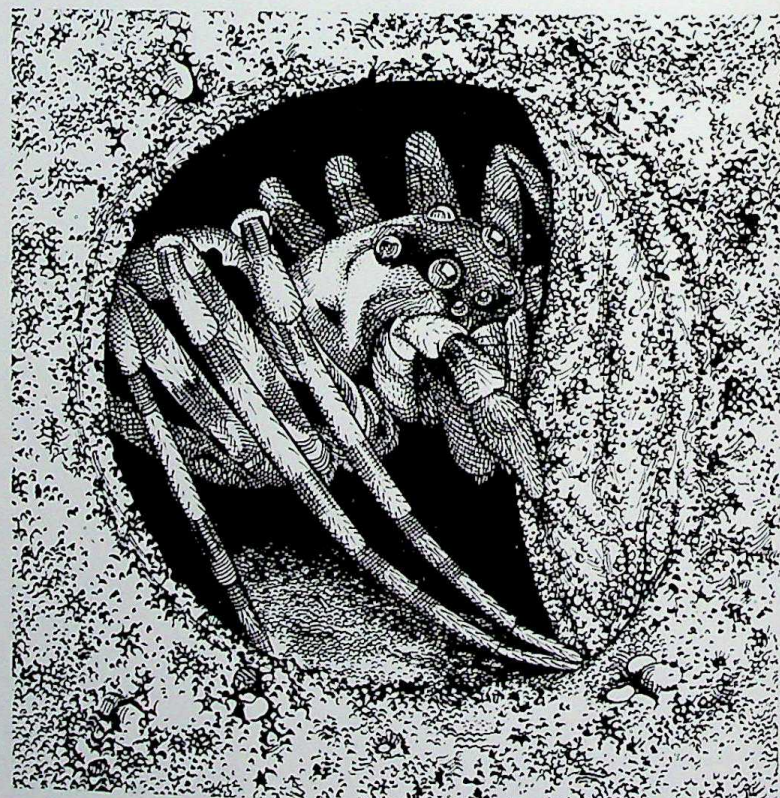
Some families of spiders have no teeth on the basal segments of their chelicerae. These spiders do not macerate their prey or reduce it to pulp. When an insect has been sucked dry through the tiny punctures made by the fangs, it still retains its original appearance and could be appropriately preserved in an insect-cabinet. These spiders usually have small fangs, and it is noticeable that they are adept at finding the chinks in highly armoured insects like weevils (*Curculionidae*), whose armour defeats most other spiders. In a leisurely way the toothless spiders explore the surface, find the joints, and insert their fangs.

The *Theridiidae* provide one example, and it is not without significance that, although these spiders build scaffolding snares, it is often only the basal portions of threads close to the ground or other surface of attachment that are provided with gum. In other words, the snares of many *Theridiidae* are specially designed to capture crawling insects. Now it is more usual for insects which spend all or most of their time on the ground to be armour-plated than for insects which spend most of their time in the air, where the extra weight would be a disadvantage, so an ability to pierce armour is of importance to a theridiid.

The toothless *Thomisidae* can grapple with weevils rejected by lycosids and other hunting spiders. Thomisids, however, often gain a quite different advantage



(a)



(b)



FIGURE 4 - (a)-(c). *Arctosa perita* pulls the silk rim of her burrow across like a curtain when alarmed, and completes the closure with a few sweeps of her spinnerets.

from not macerating their prey. Several species, including those of the genera *Misumena* and *Thomisus*, lurk in flowers whose colours match those of their bodies. Indeed, within certain limits the spider's colour will change to that of the flower—from yellow to white or *vice versa*—and this makes it inconspicuous to prey and enemy alike. When a visitor to the flower has been caught, the insect continues to look as though it were still alive all the time it is being eaten, and many a naturalist has netted a butterfly or other insect only to find that one of these crab spiders was already making a meal of it. A chewed pellet or a dismembered insect, on the other hand, would draw attention to the spider.

The actual mouth of a spider lies behind the chelicerae. It seems likely that the chitinous ridge or keel which borders the inner side of the basal segment in some spiders helps to control the flow of fluids to or from the mouth. Digestive fluids are pumped into the prey and partially digested liquids are then sucked back into the mouth.

4. BUILDING OPERATIONS

The spiders of several families excavate tunnels in the ground; the chelicerae are used to loosen and carry the earth to the surface. The British *Atypus* pushes the earth brought from underground through a closed silken tube which extends two or three inches above the ground, and then, with her long fangs protruding through the tube wall, lines the outside with grains of earth. This delicate operation performed by the fangs helps to camouflage the external portion of the tube.

Relations of *Atypus* that live in climates warmer than that of Britain often close their burrows with beautiful hinged trap-doors. The shaping of these doors is carried out by the fangs. A species in Majorca forms a series of notches along the edge of the circular door which fit exactly into grooves round the burrow's rim, and I have watched the spider (*Nemesia* sp) shaping each notch and groove with its fangs. Some of these trap-door spiders

have developed a rastellum or rake at the apex of the basal segment of their chelicerae, which is used in the excavation of burrows. With it they scrape and dislodge the earth (figure 7).

A British lycosid, *Arctosa perita* Latr., excavates a burrow in sand and lines it with silk. When she is alarmed, I have seen her seize the rim with her chelicerae and pull it across like a curtain. Then she rapidly turns round and with a few sweeping zig-zag strokes of her spinnerets closes the last chink (figure 4).

The chelicerae are used in various ways in the construction of the silken egg-sacs or cocoons. They help to shape some egg-sacs, to incorporate more or less mud as a strengthener, to plaster mud on the outside (as in the British *Agroeca*), and even to give that waterproof polished effect characteristic of the genus *Zelotes*. E. Nielsen [11] has described how a *Zelotes* holds grains of earth, moistened with saliva, in her chelicerae and rapidly rubs these over the surface backwards and forwards from the centre of the egg-sac to the circumference.

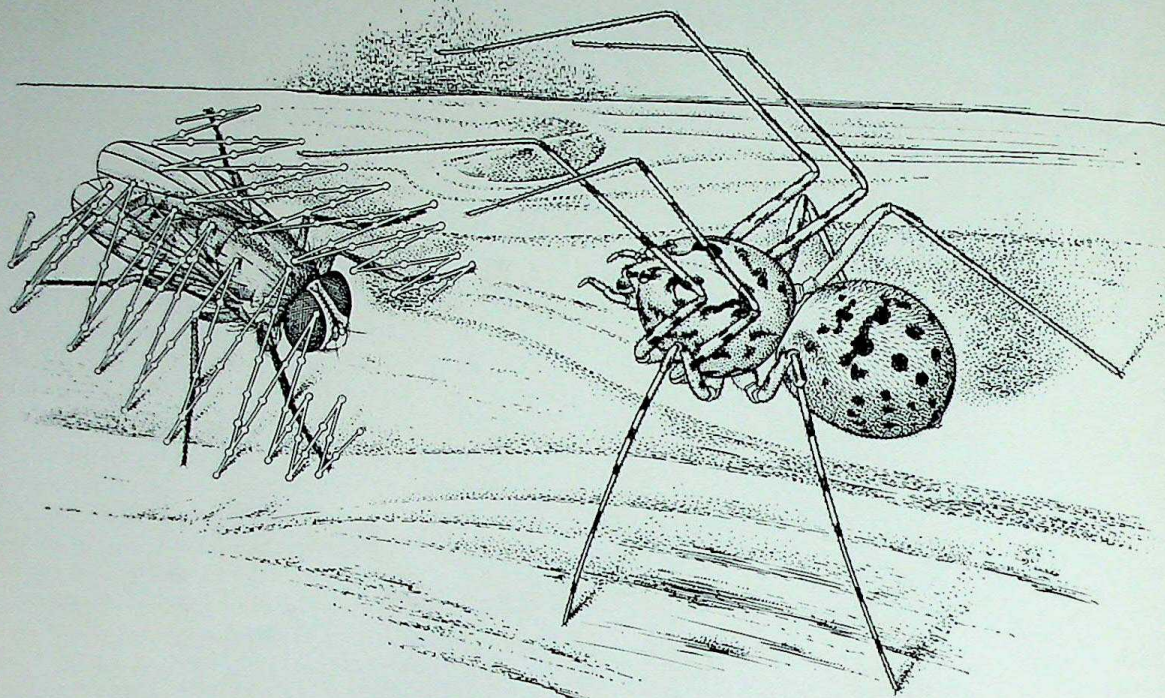


FIGURE 5 - *Scytodes* captures insects by squirting gum from her chelicerae.

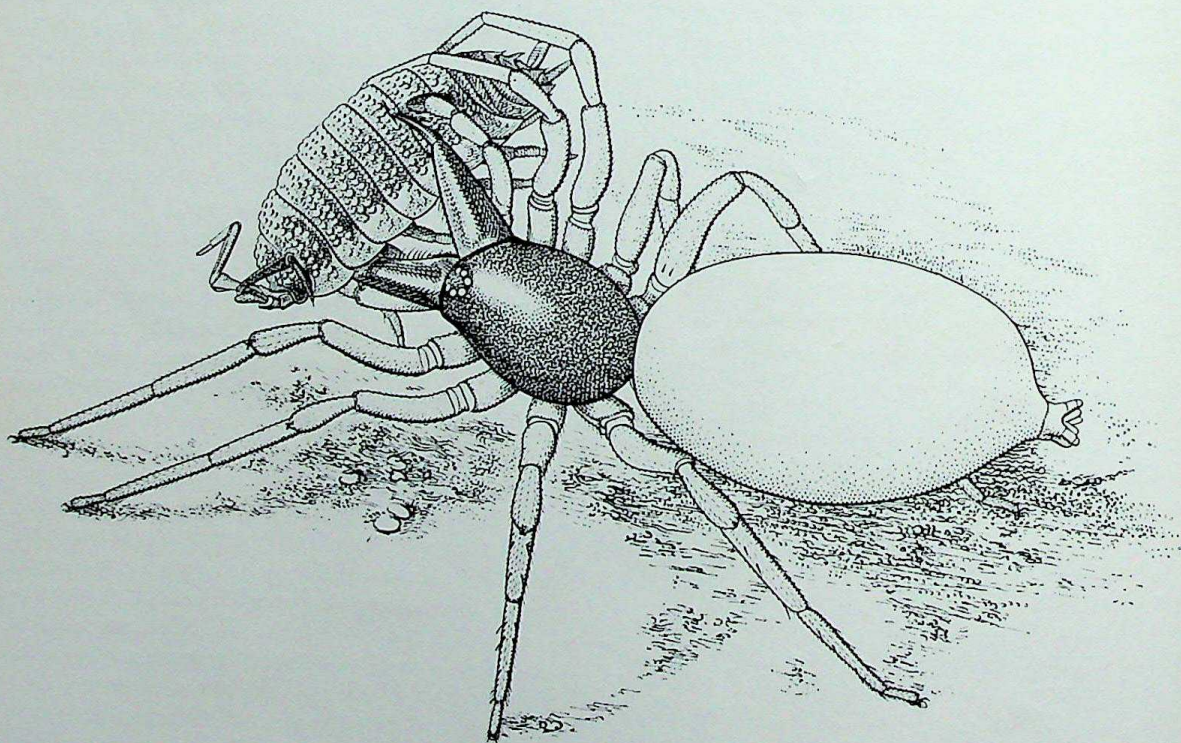


FIGURE 6 - *Dysdera*'s large fangs are well suited for gripping woodlice and piercing their armour.

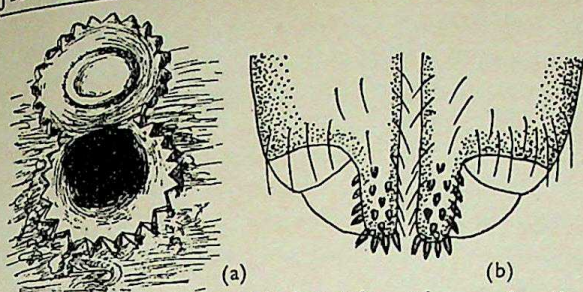


FIGURE 7—(a) The notched trapdoor of an undescribed *Nemesia* from Majorca; (b) rastellum on basal segment of the chelicerae of *Actinopus* (after J. Millot).

5. A TOOL FOR CUTTING

The chelicerae are used for tearing and cutting the spider's own threads when destroying an old snare before building a new one, or in the tidying of a new one, as for instance in the construction of the open-ring centre characteristic of the orb webs of *Tetragnatha* and *Meta*. The need to cut threads or web occurs also on other occasions, which cannot all be enumerated. Instances, however, include the occasional cutting of a hole in a sheet web as the quickest means of chasing an insect struggling on the wrong side of it (*Tegenaria*), and the cutting of an exit hole in a closed silken cell in which the spider has been resting. The fang plays a large part in operations of this kind, but the importance of the teeth seems to have been overlooked.

In *Atypus* this is specially interesting. *Atypus* lives in a closed silken tube and transfixes insects with its long fangs through the tube wall. That careful observer, F. Enock, described [4, 5] how the spider then clenches the insect against the tube and presently, after some tugging, pulls it through a neat hole in the tube wall, but he did not wrest from the spider the method by which this hole is made. Inspection of the teeth on the basal segment, however, will reveal the effect of the clenching action. Two weak lines in the silken fabric are made, each with eleven or twelve closely spaced perforations where the teeth have pierced the tube wall. A heave, and the perforations are joined, leaving two slits which lead to the two large holes made by the wide bases of the fangs. Further tugging and sawing complete the cutting of a flap in the tube wall, leaving an aperture through which the prey can be hauled.

This unique saw-like arrangement of the teeth is found in all the *Atypidae*, and is clearly an adaptation associated with their closed-tube method of capturing their prey (figure 8).

6. CLEANING THE LEGS

It is a common sight to see a spider passing the

tarsi and metatarsi of its legs through the chelicerae, during which action the chelicerae are in movement as though they were chewing. No doubt this cleans the legs, and also re-moistens them with fluid from the mouth. The thick brush of bristles with which most basal segments are furnished plays a part in this operation.

7. STRIDULATION

Stridulating apparatus has been evolved independently in several different families of spider. In some families the apparatus is associated with the chelicerae; in others it is situated between the cephalothorax and abdomen.

Sometimes stridulatory organs are present in both sexes, and are used to alarm an enemy when the spider is threatened. In other cases the organs are often present only in the male, who can be seen using them during courtship. It does not necessarily follow that the female can hear any sound—in all probability she cannot—but the rubbing of teeth against a file, for instance, will set up distinctive vibrations which pass along the threads of her snare.

Mygalomorph spiders come in the former category; the *Linyphiidae* and other web-builders are in

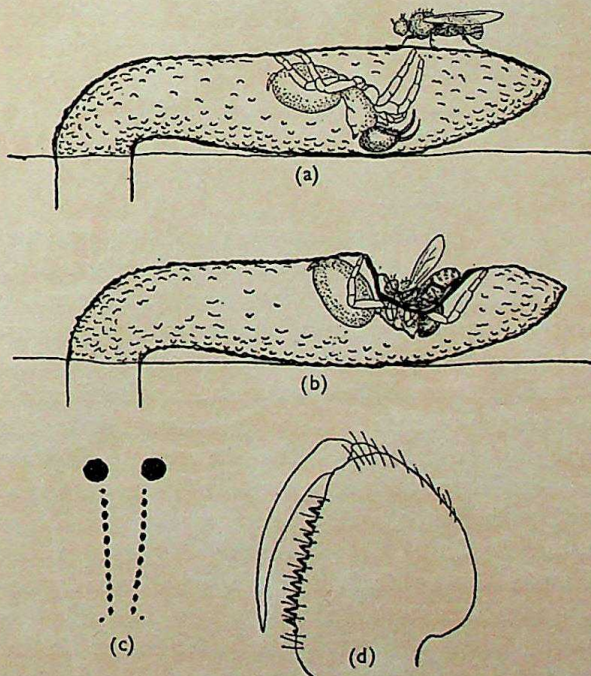


FIGURE 8—(a) *Atypus* about to strike an insect through the wall of her closed silk tube; (b) pulling and squeezing the insect against the wall. This action causes two lines of perforations (c) in the wall owing to the arrangement of teeth on the basal segment (d). Heaving, and aid from a fang, soon convert the perforations into a slit, through which the insect is pulled.

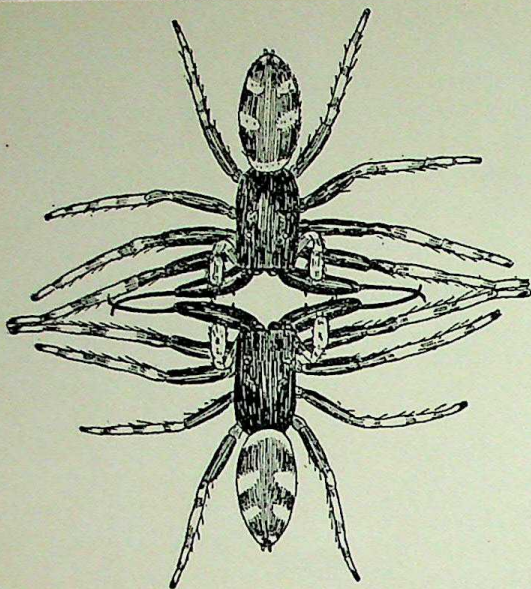


FIGURE 9—A bloodless struggle between two males of *Salticus scenicus* Linn. in which the large chelicerae are spread out laterally.

the latter. The detailed structure of the stridulatory organs varies considerably in different families, but, where the chelicerae are involved, the outer border of the basal segment bears either a file or spines of special design, which produce sound or vibrations not audible to human ears when rubbed against a tooth or special spines on the palpal femur.

8. COURTSHIP

Displays by the males are usual amongst the long-sighted hunting spiders (*Salticidae*, *Lycosidae*). The males have evolved many forms of decoration which, combined with the displays, serve to advertise their identity to their more powerful females. A continuation of the display leads to the female's submission when the sexual instincts dominate the preying instincts [3]. The decorations include enlarged leg segments, contrasting colours or tones, and tufts of hair, which, whatever they may be or wherever situated, are carefully displayed to the female. Some male salticids have greatly enlarged chelicerae. They are less efficient than normal-sized chelicerae, but in the British *Salticus scenicus* Linn. they are the only decoration not possessed by the female. During the courtship display, and during bloodless struggles between two males (figure 9), the basal segments are stretched somewhat outwards. In this position they become conspicuous to the female whom the male is facing.

9. HOLDING THE FEMALE DURING MATING

It is typical of the short-sighted male thomisids that once they find a female they do not risk losing her. Displays amongst short-sighted spiders would serve no purpose, so he boldly seizes the femur of one of her front legs and holds on until her struggles cease. No damage is done to the female's leg, perhaps because the thomisid males have no cheliceral teeth.

In the *Agelenidae* the females submit to the males and lie still after an interplay of legs. Often an agelenid male will grip a female's leg and drag her to a position suitable for mating. In some spiders the male's chelicerae are specially adapted for holding the female's chelicerae to avoid being bitten. Some species of *Dictyna* have 'bow-legged' basal segments. The female's chelicerae fit into the space so produced and are held closed.

The males of *Tetragnatha* all have a stout chitinous spur or tooth projecting outwards from their cheliceral basal segments. When the sexes come together the female opens her chelicerae as though to bite the male, and he wedges them wide open with these spurs. They mate in this position. *Pachygnatha* is a relation of *Tetragnatha* which has forsaken web-building and taken to a wandering existence. He too holds the female's fangs during copulation, but in a different manner. In the middle of each long fang is a projection on the inner side, and opposing this is a large tooth on the basal segment. When these come together a small space is left near the base of the fang. The female's fangs are imprisoned in these spaces like human wrists in a pair of handcuffs (figure 10).

10. OTHER HOLDING USES

The chelicerae fulfil many holding functions, and I shall not try to list them all. They hold the

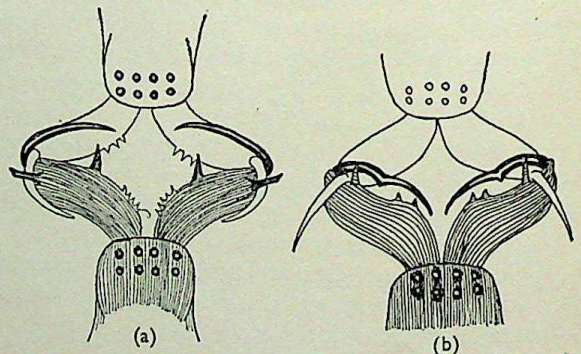


FIGURE 10—(a) A male *Tetragnatha* (shaded) holding open the fangs of the female with special teeth on the basal segment; (b) a male *Pachygnatha* handcuffing the female's fangs.

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prey, for instance, and neat punctures inside the doors of trap-door spiders show how these are held shut with the fangs (figure 7). Some spiders, including *Pholcus*, hold their egg-sacs in their chelicerae until the young hatch.

Spiders are not the only arachnids to ejaculate sperm and then, as a separate process, to transfer it to the female's body. The *Solifugae* and certain *Acarinae* which have chelate chelicerae make the transfer of the sperm with them. In spiders, the sperm is transferred by the palps. The pholcids are unique amongst spiders in holding the ejaculated sperm in their chelicerae and absorbing it thence into their palpi. In other spiders the sperm is ejaculated on to a small web, where the palps are dipped into it. May not the pholcid's chelate chelicerae, the habit, and the simple sexual organs, all be significant primitive survivals, as I suggested earlier when tracing the evolution of spiders' chelicerae?

II. UNEXPLAINED ABNORMALITIES IN THE CHELICERAE

In this survey of the uses to which chelicerae are put it is remarkable how often an unusual tooth, spur, spine, or other abnormality has been found to serve some purpose for which it has been adapted. There are, however, some cases of abnormal size in the male sex which appear to serve no useful purpose at all. Why, for instance, are the chelicerae of the males of *Linyphia triangularis* Clerck and *Theridion ovatum* Clerck larger than those of their females? All we know is that the male spiders themselves are subject to marked variations in size, and that the chelicerae of large specimens are relatively larger than those of small specimens. G. H. Locket [7, 8] has examined this allometric growth of the chelicerae mathematically in several species, and believes it to be of

frequent occurrence in spiders—as I do myself from general observation. It certainly applies, for instance, in such salticid genera as *Myrmarachne*, where the size of the male chelicerae in large specimens is almost fantastic.

It should also be mentioned that the chelicerae bear lyriform organs and a variety of different types of hair, bristle, and spine, some of which undoubtedly are sensory but whose precise function is not yet clearly understood.

SUMMARY

Ancestral arachnids had chelate chelicerae. In or before the Devonian period the immovable finger of the chelae diminished in size in some arachnids, and became a large tooth, leaving the movable finger as a fang (as in the extinct Devonian *Trigonotarbi* and the surviving orders of uropyges, amblypyges, and *Araneae*). The large tooth on the basal segment of pholcid spiders is thought to be homologous with the immovable finger of the chelae of ancestral arachnids. Very early in the history of the *Araneae*, by Carboniferous times or earlier, two types of chelicera had been developed like those found today in the sub-orders *Mygalomorphae* and *Araneomorphae* respectively. It seems probable that the latter arose from the former type by a torsion of the basal segment.

The chelicerae are used not only in attack and defence but also for macerating and dissecting prey, as tools for building operations, for cutting web, cleaning legs, stridulation, courtship, holding the female and egg-sacs, and for other purposes. In several cases the structure has become suitably modified. Attention is called to the special functions of the teeth situated on the basal segment in macerating prey, and in cutting a hole in the tube-wall of *Atypus*, and also to the manner in which *Arctosa perita* closes her burrow entrance with the help of her chelicerae.

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Book reviews

SOLVENT TOXICITY

Toxicity of Industrial Organic Solvents, by Ethel Browning. Revised edition. Pp. 411. Her Majesty's Stationery Office, London. 1953. 35s. net.

The first edition of this book (1937) is well remembered by workers in many fields, including those in industry, and brought home to many the potential dangers of solvents. This edition went rapidly out of print, to the regret of those who were unable to purchase it, and sixteen years elapsed before the edition under review appeared. A first reaction is a criticism of the length of time which has gone by—too long for a work of this importance—but on perusing the pages one is impressed by the great amount of work which the author has accomplished and the vast literature which has been examined and listed. Space does not permit of full justice being done to the book here, but it is clearly one which should be in the hands of those responsible for industrial health, and be available to all those in control of factories using solvents.

Each monograph aims at giving the essential physical constants; the uses; the toxicity, acute and chronic, to man and animals; the allowable concentration in air and in many cases its determination; and the pathological effects upon the tissues of the body.

The reviewer feels that the work should be a very valuable guide in controlling factory conditions, so that the earliest toxic effects may be noted before the onset of serious illness and possibly death. To those who wish to study in detail the toxicity of any particular solvent it may be noted that there are over 42 pages of references, containing more than 1500 names.

In conclusion, an especial word of thanks and congratulations must be extended to the author.

G. ROCHE LYNCH

HOW FUNGI SPREAD

Dispersal in Fungi, by C. T. Ingold. Pp. 197, with half-tone and line illustrations. Clarendon Press, Oxford. 1953. 18s. net.

In Professor Ingold's earlier book, 'Spore Discharge in Land Plants' (1939), approximately half the text dealt with the fungi. This portion has now been revised and extended, to provide a comprehensive survey of the dispersal of fungus spores.

An 80-page chapter on spore liberation gives detailed accounts of the orientation of spore-releasing surfaces and of the functioning of the diverse structures responsible for spore discharge. The emphasis is on the mechanisms of ascospore ejection, but the chapter includes descriptions of the 'water rockets' of *Basidiobolus*, the 'catapult' of *Sphaerobolus*, and other more conventional types of spore release found in the *Phycomycetes* and *Basidiomycetes*.

The account of the further dispersal of the liberated spores is continued under the headings of spore distribution in the air; dispersal by insects and by larger animals; seed-borne fungi; and dispersal by water. This last chapter gives a brief but fascinating glimpse into the author's recent work on the aquatic fungi. There is an up-to-date bibliography of 142 titles.

The text is admirably partnered by eight plates and ninety line figures, most of which are original. These have the animation appropriate to the subject and reflect something of the enthusiasm with which Ingold's book is inspired.

R. W. MARSH

ONE VIEW OF SOIL RESTORATION

Soil Restoration, by Edward Faulkner. Pp. 208. Michael Joseph, London. 1953. 10s. 6d. net.

In his final chapter the author writes: 'To many a reader I shall seem to be a cultist of the worst order. Naturally to myself I seem anything but that. Perhaps it is somewhere between that the truth lies.' Most of the book falls definitely within the cultist category. Mr Faulkner gives a somewhat rambling account of what he terms the restoration of a small patch of land, but he has certainly taken the long and hard way regardless of cost, and we are asked to believe that the effort was justified by the freedom of the crops from diseases and pests and the quality of the produce. Most of the theories he propounds are far from original and there is good scientific evidence to show that some of them are thoroughly unsound. Long before Mr Faulkner wrote 'Ploughman's Folly' it was well known that, under certain circumstances, other forms of cultivation are better than ploughing, but practical experience and careful experimentation have shown that, in general, the plough

performs a very useful function. The value of composts is well understood, but surely it is not seriously suggested that food production could be maintained at present levels with crop residues and composts supplemented by underground water 'loaded with minerals of every kind'? There is too much fancy in this book and too little fact.

W. G. OGG

LIFE OF KEPLER

Johannes Kepler: Life and Letters, by Carola Baumgardt, with an introduction by Albert Einstein. Pp. 209. Victor Gollancz Limited, London. 1952. 12s. 6d. net.

This interesting book is essentially a short biography of Kepler, which includes the first translations into English of a selection of his letters. This feature greatly enhances its value. The author leaves to Einstein the assessment of Kepler's scientific work, which is made in a short introduction, while she herself is primarily concerned with presenting to her readers Kepler the man, as revealed in his struggles against the difficult circumstances of his life and times, and in his correspondence.

Prematurely born, always in frail health, his sight severely impaired through smallpox, inadequately paid and sometimes not paid at all in the various posts that he occupied, maintaining himself when necessary by calendars and prognostications, a liberal Protestant when all tolerance was suspect, and moreover a follower of the heretical Copernican theory, discoverer of the laws of planetary motion that have since immortalized his name but which had little interest for his own age, his last years harrowed by the charge of witchcraft brought against his mother: such were Kepler's trials, yet, as these letters show, he never lost his lightheartedness, his sensitivity of mind, his belief in God as the source of the spiritual and physical laws of the universe.

A well written book which, for English readers, sheds much light on Kepler's personality.

D. MCKIE

CHRISTIANITY AND SCIENCE

Christianity in an Age of Science (Riddell Memorial Lectures), by C. A. Coulson. Pp. 53. Oxford University Press, London. 1953. 5s. net.

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Professor Coulson asks what status should be granted to religion in an age of science: and answers the question by considering the way in which a man of science approaches the whole question of reality and truth, showing that it provides a natural approach also to religion. To the man of science, his experiences are primary, and his scientific constructions (electrons, genes, and so on) are introduced in order to relate the experiences together into a satisfying and orderly scheme. There are, however, patterns other than the scientific, equally good at co-ordinating experiences. Thus when a man says 'The concept of a personal God enables me to relate together many of my most profound experiences,' his attitude is essentially the same as that of the man of science. The process by which we attain a belief in God is of the same character as the process by which we attain a belief in the existence of the minds of our fellow-men. From these beginnings, the author develops a view of the coherence of all reality, with God as the integrating principle within whose being scientific laws, artistic efforts, and personal religious experiences are different facets of one whole.

EDMUND WHITTAKER

MIND AND BRAIN

The Neuropsychological Basis of Mind, by J. C. Eccles. Pp. 314, with line illustrations. Oxford University Press, London. 1953. 25s. net.

This book, reproducing eight lectures which Professor Eccles delivered in the Hilary Term of 1952 in Magdalen College, Oxford, is really an astonishing achievement. His aim, as the main title indicates, was to find some clue to the missing link between the activities of the brain, as these are now being progressively analysed with all the refinements of the most advanced physiological technique, and those activities which we attribute to the mind, and of which our knowledge seems to us the most direct, and independent of any sensory mediation. Evidence accumulates ever more rapidly of the intimate dependence of these mental processes on the functional integrity of the brain, with its fantastically complicated traffic of excitation and inhibition across its almost inconceivably numerous synapses. The meaning of this intimate relation between sequences of events which seem to be essentially disparate may be regarded, by physiologist and philosopher alike, as the ulti-

mate mystery to be explored; but, hitherto, the greatest followers of either discipline have seen no prospect of finding a clue to it. Some might be content to doubt whether man's conscious mind will ever be able to unravel the almost infinitely complex chain of material happenings in the brain, on which the mind's activities somehow and so intimately depend, and thus to escape from the illusions of spontaneity, volition, and free will. Watching movements of an amoeba, we find it difficult not to regard some of them as 'voluntary,' though we do not hesitate to give them a material, deterministic interpretation. We ourselves cannot unravel even this chain, and we certainly do not expect the amoeba to do so.

Eccles is not disposed, however, to recoil from the mystery, as thus intangible. On the contrary, he prepares his Magdalen audience for an attempt to solve it, by laying a most elaborate groundwork of the latest physiological analysis of the activities of the whole nervous system, including a description in outline of the relevant features of its anatomy. For such a presumably mixed audience, the chapters representing these seven lectures, and leading up to the essential problem in the eighth, might be regarded by some as overloaded with detail. A physiologist, on the other hand, may applaud them as a *tour de force*, and admire, by the way, Eccles' skill as a leading advocate now, in chapters III and IV in particular, of a conception to which, until his recent and sudden conversion, he offered a stubborn and stimulating resistance. With sympathy for the shorn lambs among his readers, he himself suggests, in his preface, some very extensive skipplings in these specially physiological chapters, to come the more rapidly, in chapter VIII, to the heart of his chosen problem.

Can the reader expect to be satisfied that Eccles has come nearer than any of his distinguished predecessors to a solution of this problem—to the discovery of an intelligible link between orders of experience apparently so incompatible? Honestly, it has to be doubted. 'The neuropsychological hypothesis,' he writes (p. 277), 'is that the "will" modifies the spatio-temporal activity of the neuronal network by exerting spatio-temporal "fields of influence" that become effective through this unique detector function of the active cerebral cortex.' One feels bound to suspect that the mind of the reader would have to be rather deeply

benumbed and bemused by the luxuriance of technical expositions in earlier chapters before he could begin to feel satisfied by this. Eccles does not shrink, however, from what seems to be the simple meaning of such an impressive pronouncement. What we know as mind is clearly somehow dependent on material happenings which we record with increasing precision of detail in the brain; to understand how it is so, we have only to suppose, it appears, that the mind can exercise spatio-temporal 'fields of influence' (whatever that may mean) on material events; and, as evidence of the admissibility of such an assumption, Eccles cites the now well known statistical claims for a 'psychokinetic' influence of mind on the fall of dice, etc.

Convincing? Not to the reviewer, by a long way. But nobody interested in such problems can afford to miss Eccles's masterly assembly of physiological data, or can fail to admire his courage and his independence of tradition.

H. H. DALE

A CHEMICAL ENCYCLOPAEDIA

Encyclopedia of Chemical Reactions, compiled and edited by C. A. Jacobson with the assistance of C. A. Hampel and E. C. Weaver. Vol. 5. Pp. 787. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1953. 120s. net.

The present volume of the series deals with the elements nickel to ruthenium in alphabetical order. The text consists of statements of the reactions, accompanied by chemical equations and references to the sources in each case. In the case of nickel carbonate, for example, the formula NiCO_3 is repeated as heading, and below is the symbol of the reactant in each entry. In some cases, details of the way the reaction is carried out are given. There are indexes of reagents and of substances obtained. The volume has been compiled from the literature by 118 abstractors. The book is well printed on good paper and strongly bound, so that it should withstand laboratory use.

Many of the reactions are well known, but in general the reference is to the latest publication dealing with a specific reaction, so that in this way it is possible to infer that a statement in an old source has been checked. In some cases the information, although brief, is detailed enough to serve as a guide to a preparation. In other cases

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the reactions are of interest in chemical analysis, when the procedure to be used in the test is stated.

It should be obvious that the work is not intended to replace the existing treatises on inorganic chemistry, but to provide in a compact form a body of information which may be required at short notice in a laboratory, and it would seem to fulfil its object very well. Every reader will find matters of detail which can be criticized, but on the whole the series of volumes is likely to serve a useful purpose. If they are available in a laboratory their use may save a good deal of time which would otherwise be spent in searching through more bulky literature. The reviewer found a large number of reactions listed which were unknown to him, and the existence of which he would not have suspected, and the scope of the book is wide enough to make it appeal to the specialist. Jacobson did not live to see the completion of his work, but the other two editors promise to carry on the series. The reviewer thinks this is a useful book which should be available in every chemical laboratory.

J. R. PARTINGTON

STARCH

Starch and its Derivatives, by J. A. Radley. Vol. 1 (3rd edition). Pp. 510, with half-tone and line illustrations. Chapman and Hall Limited, London. 1953. 65s. net.

This volume constitutes a genuine revision of the second (1943) edition, and a large amount of new material has had to be surveyed. The author has been assisted by nine well known carbohydrate chemists, and the book is therefore authoritative. There are a chapter by S. Peat on the biological function of starch, and an excellent synopsis, by L. Hough and J. K. N. Jones, of the chemical evidence for the structures of the components of starch.

Particularly interesting is the collaboration of American chemists, who deal with the starch fractions, the waxy cereals and starches which stain red with iodine, dextrins and dextrinization, and the esters and ethers of starch, these latter contributions being by E. F. Degering.

Later chapters are concerned with amylases. After discussing the general problem, Radley describes the preparation of enzymes used in the starch industry, and the action of α - and β -amylases on starch.

The various approaches to the starch

problem are followed, so that the present volume will be attractive to both academic and industrial chemists. References to the literature are copious, though carefully selected. In spite of its divided authorship the book has a pleasant coherence. The volume is unusually free from typographical errors, but the uncritical use of the words 'corn' and 'maize' is a little irritating. In the editorial preface there is some rather unsound dogma about the value of scientific papers.

E. E. TURNER

ROTATING LIQUID MASSES

The Stability of Rotating Liquid Masses, by R. A. Lyttleton. Pp. 151, with line illustrations. Cambridge University Press, London. 1953. 35s. net.

In 1687 Newton explained precession as due to the attraction of the Sun and Moon on the equatorial protuberance of the Earth, regarded as an oblate spheroid, and half a century afterwards Maclaurin showed that the oblate spheroid is a possible figure of equilibrium for a rotating fluid mass. The subject thus opened up has been greatly developed in the last two hundred years. Jacobi showed that an ellipsoid with three unequal axes is also a possible form of equilibrium, and Sir George Darwin studied what he called the 'pear-shaped' figures, while Poincaré, followed especially by Jeans, examined the stability of the known forms. These investigations seemed to indicate that a rotating liquid might ultimately divide into two detached portions in orbital motion about each other, and an explanation might thus be provided for the origin of binary stars—a theory that was expounded in Jeans's books on cosmogony of 1919 and 1929.

Lyttleton concerns himself mainly with this problem of the evolution of gravitating liquid masses, and his principal achievement is to show that the dynamical evidence is against the fission process. The last chapter contains an interesting discussion of some views on the origin of the planets and satellites.

EDMUND WHITTAKER

EPIGENETICS

The Epigenetics of Birds, by C. H. Waddington. Pp. 272, with line illustrations. Cambridge University Press, London. 1952. 35s. net.

The study of heredity has proved that the development of the fertilized egg is determined by what is inside it.

The study of this determination, its analysis into separate processes, is what Waddington describes as 'epigenetics.' Its beginning requires us to recognize the division between nucleus and cytoplasm within the cell, the localization of materials, their limited and variable diffusion, and the consequent chemical gradients within and between cells. Its further developments require us to note the genetic character of cell-lineages and of infectious particles both in normal development and in the growth of tumours. Its present controversies deal with the immunological character of tissues, with the reactions of fixed cell-constituents and diffusing hormones, and with the imitation of genetic effects by timed experimental treatments.

These notions give an inductive unity to the study of development in all animals and even, to some extent, in plants. But so diverse are the materials and so variously co-ordinated are the processes, that there is probably room for detailed descriptive reviews of small aspects of the techniques and limited sections of the literature. This is the line the author has followed in confining himself to birds, and more particularly to recent work on the manipulation of the chick embryo. This field, however, has proved to be theoretically one of the least rewarding in embryology. The result is, therefore, although most conscientiously prepared, none the less inevitably diffident and even depressing. It makes one ask whether the term epigenetics, with its suggestion of fundamental genetic principles, is not premature and somewhat misleading. One certainly ends with the uncomfortable feeling that this term alone is not enough, with the best will in the world, to induce or evoke or organize a science.

G. D. DARLINGTON

THE U.S. PACIFIC COAST

Between Pacific Tides, by E. F. Ricketts and J. Calvin. (Third edition, revised by Joel W. Hedgpeth.) Pp. xiv + 502, with 134 text figures and numerous plates. Stanford University Press, California; Geoffrey Cumberlege, London. 1953. 48s. net.

It is a pleasure to review this book, which has become a unique feature in the history of biological publications. It is the first popular book to have described the intertidal zonation along a whole coastline as long as that of the Pacific coast of the United States, and the distribution and natural history of the animals in relation to this. It has

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had a well deserved success since its first edition appeared in 1939, and although popular in form is indispensable to professional biologists and students. The principal author, E. F. Ricketts, suffered an untimely death in a motor-accident. As he was an unconventional naturalist of genius, and a character of unusual distinction, his loss is a serious one. It is a little mitigated by the fact that in the new edition, edited by Joel Hedgpeth, we are presented with personal details about Ricketts which will have been unknown to many of his readers. Dr Hedgpeth has edited the work very capably, and has added welcome sections on seaweeds and on the general question of intertidal zonation.

T. A. STEPHENSON

LIFE OF BUFFON

Buffon, by L. Bertin, F. Bourdier, E. Dechambre, Y. François, E. Genet-Varcin, G. Heilbrun, R. Heim, J. Pelseneer, and J. Piveteau. Edited by R. Heim. Pp. 246, with half-tone illustrations. Publications Françaises, Paris. 1952. Fcs. 900 net.

Buffon's complex and remarkable personality could be truly depicted only by a collection of qualified specialists. F. Bourdier deals with the main aspects of Buffon's life and work. In a chapter full of surprises, L. Bertin discusses the manifold activities of Buffon as man of affairs. Y. François's chapter is entitled 'Buffon and the royal gardens'; he outlines Buffon's tremendous task in raising the gardens to the status of a first-rate scientific establishment, a task which represents one of the great naturalist's principal claims to remembrance. J. Piveteau analyses Buffon's religious notions and his successive attacks on the problems of materialism and spirituality. J. Pelseneer deals with Buffon as metaphysician in discussing an unpublished letter to Guyton de Morveau on the phlogiston theory. Mme Genet-Varcin paints a brief picture of Buffon's ideas on the generation of living creatures. E. Dechambre takes as his subject the article on dogs in the *Histoire Naturelle*, and brings before us the great experimenter and forerunner of modern biologists. Finally, the man himself is revealed in F. Bourdier's chapter on the portraits of Buffon, which also contains a number of unpublished letters. The bibliography of Buffon's publications drawn up by G. Heilbrun shows us the gradual unfolding of this great body of thought.

To unify this collection, some kind of general summary is required. This is provided by R. Heim's preface, in which he brings together the essentials of the rest of the book in a masterly synthesis of the man and his work, his ideas, and his philosophy of life. From this admirably produced volume there emerges the figure of Buffon, hitherto all too little known, yet one who has contributed in no small degree to our knowledge of the world and its mysteries.

MAX VACHON

WOOD CHEMISTRY

Wood Chemistry, edited by L. E. Wise and E. C. Jahn. Second edition. Pp. 1277 + indexes, with half-tone and line illustrations. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1952. In two volumes, 120s. net each.

A knowledge of the relevant basic chemistry is becoming increasingly important to all concerned with the utilization of wood, whether as a raw material for chemical industry or for constructional purposes. Soon after its appearance in 1944, the American Chemical Society's Monograph No. 97, 'Wood Chemistry,' became recognized as the standard work on this subject. Developments in recent years have been so rapid that in preparing a second edition of this monograph it has been found necessary to expand it into two volumes.

The whole work has been carefully revised, and many of the chapters, each of which is written by a specialist, have been considerably enlarged, or completely rewritten under new authorship, in order to bring them up to date. New chapters have been added on some aspects of the subject. The fundamental chemistry of wood is dealt with in volume I, which includes a comprehensive treatment of the chemistry of the major components (cellulose, the hemicelluloses, and lignin) and the minor components of wood. The latter section provides a valuable and unique account of the wide range of types of organic compounds found among the extraneous components of wood.

In volume II the applied aspects of the subject are fully discussed. These include not only the different branches of industrial wood chemistry, but the surface properties of cellulosic materials, the decomposition of wood by micro-organisms, and the chemical analysis of wood. While the many valuable features of the earlier edition

are retained and in many cases improved upon, perhaps the outstanding new contributions are a chapter by H. Erdtman on the relationship between the extraneous components of the heart-wood of conifers and their taxonomy, and a masterly review by W. G. Campbell of the biological decomposition of wood, containing much material not previously assembled in one article.

The production is of a high standard and the monograph is very fully documented. It is provided with a subject index, but there is no author index.

R. H. FARMER

PLANT GEOGRAPHY

Manual of Phytogeography, by Léon Croizat. Pp. viii + 587, with 105 plant-distribution maps and one figure. Dr W. Junk, The Hague. 1952. Fl. 45; 90s. net.

In a comprehensive work on plant geography a reasonable expectation would be to find a statement of basic principles and working methods, and indications of the new conceptions and interpretations, set forth in such a manner as to be of interest not only to the specialist but to the general reader, for an essential feature of this branch of botany is that it is of general interest and lies well within the general comprehension. Let it be said at once that these expectations are fulfilled in this very lively and interesting book. The author has approached his subject with a wide knowledge of taxonomy and general botany, and a keen interest and curiosity regarding the distribution of plants in space and time—phenomena that are certainly among the most enigmatic and thought-provoking with which the botanist has to deal. The author has a strong conviction regarding his conclusions, and he does not hesitate to express disagreement with the views of others.

The means of plant dispersal by the various agencies are almost certainly not as simple as has been supposed; indeed, some species have no very evident means of dispersal, yet they have become widely distributed, and are, in fact, self-dispersing from centres of origin. It was essentially this kind of problem that engaged the author's interest, and he has attempted to provide scientific explanations by the scrutiny of the relevant data for hundreds of different groups and families. The results of this monumental undertaking are set out in over three hundred pages of taxonomic and geographical

data, illustrated by many charts. The author is well aware how large is this task and how numerous are the pitfalls, and he has duly safeguarded his position; but he has undoubtedly made a significantly constructive contribution to his major theme of 'presenting a global picture of plant dispersal in space and time.' The basic data are the records of plant distribution and taxonomic relationships; from these, important generalizations regarding plant migration can be drawn. Croizat's approach is simple, but it leads to imaginative and far-reaching reconstructions, the validity or non-validity of which will become evident with the passage of time and the pursuit of further investigations. In this work the concept of *genorheiron* has a central place, i.e. that 'streams of plant life, laden with evolutive potential,' yield varieties, species, and genera at points along the track of dispersal, the whole constituting an orderly biological process. In the author's view, phytogeography is concerned not only with the interpretation of plant dispersal, but with how plants evolve during that process.

Briefly, the author concludes that the great contemporary angiosperm flora originated in the pre-Cretaceous continent of Gondwana (which occupied practically the whole of the modern Indian Ocean), and that access was thence afforded to each of the great continental masses of today. Plant migrations are held to be 'orderly, precise and repetitious,' having taken place from centres of dispersal in the former unified southern continental mass. Whether the author's major conclusions are right or wrong is a matter which only the future can decide, but meanwhile this vigorous and imaginative book can be recommended as a clear and, indeed, entertaining statement of the essential problems.

C. W. WARDLAW

'WORLD LIST'

World List of Scientific Periodicals Published in the Years 1900-1950, edited by W. A. Smith and F. L. Kent, assisted by G. B. Stratton. (Third edition.) Pp. 1058. Butterworths Scientific Publications, London. 1952. 12 guineas net.

This edition of the 'World List' contains the titles of some 14 000 more periodicals than did the second edition of 1934. The war period of 1939-45 saw the temporary eclipse of many old-established journals, and in continental

Europe in particular the post-war years have witnessed their revival or their re-emergence in new and sometimes unfamiliar forms. The appearance of a new list is thus most welcome.

The editors claim to include only journals dealing with natural sciences, a term which they have perhaps interpreted rather liberally, for it is hard to understand how, for example, such publications as 'Hunting, Camping and Fishing' of Illinois or *Vins de luxe exotiques* of Paris are allowed to rub shoulders with the academic proceedings of the scientific societies of the world. However, the use of 'World' in the title is amply justified, for the inclusion of say the 'New Guinea Agricultural Gazette' of Rabaul or *Gronlandsposten* of Godthaab, testifies to the immense effort made to procure an exhaustive survey of world scientific literature.

The layout closely follows the lines of the second edition, but although a number of inconsistencies have been removed, several minor irritations persist. The 'World List' should and does serve as a model for bibliographers in the abbreviation of titles of periodicals; it is difficult, however, to appreciate the subtle distinction made between the use of the abbreviation *roy.* for Royal in the 'Proceedings of the Royal Society of Victoria' and that of *R.* in those of the Royal Society of Medicine. The eye is arrested from time to time by disconcertingly large blocks of Russian journals whose titles are quite wisely printed in their original Cyrillic characters, followed in most cases by a transliteration. The alphabetic order, however, in which these publications are listed presupposes a knowledge on the part of the searcher of the 'English' system of Cyrillic transliteration; thus the *Ж* of *Журнал* is treated as equivalent to *Zh*, under which the journal will then be found. It would have enhanced the already great value of the book if a recognized international method of transliteration had been followed.

G. N. J. BECK

CHROMATOGRAPHY

Chromatographic Methods of Inorganic Analysis, by F. H. Pollard and J. F. W. McOmie. Pp. viii + 192, with half-tone and line illustrations and colour frontispiece. Butterworths Scientific Publications, London. 1953. 30s. net.

Practical Chromatography, by R. C. Brinley and F. C. Barrett. Pp. 128, with half-tone and line illustrations. Chapman and Hall Limited, London. 1953. 15s. net.

The immense amount of chromatographic work which has now been done throughout the world is reflected in a scattered literature so large as to intimidate the newcomer and to be an unwieldy burden even for experienced workers. There is, therefore, a real need for critical and concise books which reduce the subject to manageable proportions.

It is an indication of the way in which the field has expanded that advanced books now tend to concentrate not upon the whole subject but upon the various subdivisions—such as partition or ion-exchange chromatography—of which the authors have special knowledge. One subdivision which has recently grown very rapidly is that of inorganic chromatography. Although the earliest work in this field may be traced back to Runge, more than a century ago, it is only within the last decade that it has been intensively—and very profitably—explored, and much of the literature is of recent origin. Among the various centres at which inorganic chromatography has been the subject of intensive investigation Bristol is outstanding, and a book from two of the principal workers there is thus particularly welcome. Of 'Chromatographic Methods of Inorganic Analysis' it may be said that it presents clearly and concisely all that one could reasonably expect to find in a volume with this title. Its approach is essentially practical, though there are chapters on such general subjects as the history and the principles of chromatography. Time and again one is made aware of the fact that the authors have encountered difficulties, solved them by simple techniques and devices, and unobtrusively passed on the benefits of their wide laboratory experience to the reader. This book can be warmly recommended to all workers in this field.

'Practical Chromatography' is, as its title indicates, a handbook of laboratory practice. It is, not unnaturally, strongest in the fields in which its authors' main interests lie, and this tends to make it a little unbalanced. Thus treatment of reversed phase chromatography is too brief, even allowing for the novelty of the field. On the other hand, the discussion of gas chromatography draws timely attention to a field which still awaits adequate exploration. Practical requirements are borne constantly in mind, and the reader will find many useful hints on technique and apparatus.

TREVOR I. WILLIAMS

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Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

Biological Transformations of Starch and Cellulose, edited by R. T. Williams. Pp. 84. Biochemical Society Symposia No. 11. Cambridge University Press, London. 1953. 10s. 6d. net.

General Biochemistry, by Joseph S. Fenton and Sofia Simmonds. Pp. xii + 940. Chapman and Hall Limited, London. 1953. 80s. net.

BIOLOGY

A Hundred Years of Biology, by Ben Dawes. Pp. 429. Gerald Duckworth and Company Limited, London. 1953. 30s. net.

Kosmos-Lexikon der Naturwissenschaften, A-K. Pp. 1591. Kosmos Gesellschaft der Naturfreunde; Franckh'sche Verlagshandlung, Stuttgart. 1953. Half-linen, DM. 29.50; half-leather, DM. 36 net.

Le Mécanisme de la Vision des Couleurs, by J. Ségal. Pp. 347. G. Doin et Cie., Paris. 1953. Fcs 3000 net.

The Metabolism of Algae, by G. E. Fogg. Pp. 149. Methuen and Company Limited, London. 1953. 8s. 6d. net.

Nucleo-Cytoplasmic Relations in Micro-Organisms, by Boris Ephrussi. Pp. viii + 127. Oxford University Press, London. 1953. 18s. net.

Traité de Paléontologie, Vol. III, edited by Jean Piveteau. Pp. 1064. Masson et Cie., Paris. 1953. Paper covers, fcs 9600; bound, fcs 10,320 net.

BOTANY

Intermediate Botany, by L. J. F. Brimble. (4th edition, revised and rewritten in collaboration with S. Williams and with the assistance of G. Bond.) Pp. 505. Macmillan and Company Limited, London. 1953. 20s. net.

CHEMISTRY

Analisi Fisico-Chimiche, I, by G. Buogo (2nd ed. revised). Pp. 302. Sansoni Edizioni Scientifiche, Florence. 1953. L. 2500 net.

Chemistry and Man, four lectures by C. N. Hinshelwood, R. P. Linstead, the late J. Drummond, and J. W. Cook. Pp. 88. E. and F. Spon Limited; The Chemical Council, London. 1953. 7s. 6d. net.

Formaldehyde (2nd ed.), by J. Frederic Walker. Pp. 575. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1953. 96s. net.

The Furans, by A. P. Dunlop and F. N. Peters. Pp. 867. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1953. 144s. net.

Notions Élémentaires de Chimie Générale à la Lumière des Théories Modernes, by Paul Pascal. Pp. 550. Masson et Cie., Paris. 1953. Fcs 3600 net.

Organic Chemistry, Vols. III and IV, edited by Henry Gilman. Pp. 580 + xxxviii and 665 + xxxviii. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1953. 70s. each volume.

Organic Chemistry, by P. B. Sarkar and P. C. Rakshit. 7th edition, revised by P. B. Sarkar. Pp. 598. H. Chatterjee and Company Limited, Calcutta. 1953. 8 rupees net.

Organic Reactions, Vol. VII, editor-in-chief Roger Adams. Pp. 440. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1953. 72s. net.

Progress in Organic Chemistry, Vol. 2, edited by J. W. Cook. Pp. 212. Butterworth's Scientific Publications, London. 1953. 42s. net.

Structure and Mechanism in Organic Chemistry, by C. K. Ingold. Pp. 828. G. Bell and Sons Limited, London. 1953. 77s. 6d. net.

GENERAL

Cybernetics (9th Conference), edited by H. von Foerster. Pp. 184. Josiah Macy Jr Foundation, New York. 1953. \$4 net.

Un Demi Siècle de Progrès dans les Travaux Publics et le Bâtiment, 1903-1953. Pp. 211 + cxi. Le Moniteur des Travaux Publics et du Bâtiment, Paris. 1953. Fcs 1400 net.

The Hand Produced Book, by David Diringer. Pp. 603. Hutchinson's Scientific and Technical Publications, London. 1953. 60s. net.

Preservazione e Conservazione degli Alimenti, by Giulio Buogo. Pp. 221. Editori-Carlucci, Bari. 1953. L. 1800 net.

GEOLOGY

A Manual of Australian Soils, by C. G. Stephens. Pp. 48. Commonwealth Scientific and Industrial Research Organization, Australia. Melbourne. 1953. 25s. net.

Pédrographie des Roches Sédimentaires, by Albert Carozzi. Pp. 250. F. Rouge et Cie., Lausanne. 1953. S. fcs 23.40 net.

The Soils of Europe, by W. L. Kubišna. Pp. 317. Consejo Superior de Investigaciones Científicas, Madrid; Thomas Murby and Company, London. 1953. 75s. net.

HISTORY OF SCIENCE

Chymia—Annual Studies in the History of Chemistry, Vol. 4, edited by Henry

M. Leicester. Pp. 217. University of Pennsylvania Press, Philadelphia; Geoffrey Cumberlege, London. 1953. 36s. net.

Hallstatt und die Hallstattzeit, by F. Morton. Pp. 122. Verlag des Musealvereines, Hallstatt. 1953. 25s. (Austrian).

Justus von Liebig, by Herta von Dechend. Pp. 141. Verlag Chemie, GmbH, Weinheim. 1953. DM. 8.40 net.

Un Pionnier de la Physiologie, by Léon Fredericq. Pp. 232. Masson et Cie., Paris. 1953. Fcs 1345 net.

PHYSICS

Experimental Nucleonics, by Ernest Bleuler and George J. Goldsmith. Pp. 393. Sir Isaac Pitman and Sons Limited, London. 1953. 30s. net.

History of the Theories of Aether and Electricity—The Modern Theories 1900-1926, by Sir Edmund Whittaker. Pp. 319. Thomas Nelson and Sons, Edinburgh. 1953. 32s. 6d. net.

Standard X-ray Diffraction Powder Patterns. Volume I, by Howard E. Swanson and Eleanor Tatge, pp. 95; Volume II, by Howard E. Swanson and Ruth K. Fuyat, pp. 65. U.S. Government Printing Office, Washington. 1953. 45 cents each volume.

TECHNOLOGY

Chemical Process Machinery (2nd ed.), by E. Raymond Riegel. Pp. 735. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1953. 100s. net.

Principles of Electronics, by L. T. Agger. Pp. 340. Macmillan and Company Limited, London. 1953. 18s. net.

Reviews of Petroleum Technology 1951. Pp. 360 + viii. Institute of Petroleum, London. 1953. 50s. net.

ZOOLOGY

The Behaviour and Social Life of Honeybees, by Ronald Ribbands. Pp. 352. Bee Research Association Limited, London. 1953. 21s. net.

Clasificación General de los Dípteros, by Rafael Gonzalez-Rincones and Luisa Guyon. Pp. 243. Universidad Central de Venezuela, Caracas. 1953. Bs. 15 net.

Gli Animali Commestibili dei Mari d'Italia, by Arturo Palombi and Mario Santarelli. Pp. 349. Ulrico Hoepli, Milan. 1953. L. 3800 net.

How Animals Move, by James Gray. Pp. 114. Cambridge University Press, London. 1953. 16s. net.

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Institute of Animal Genetics, University of Edinburgh. In 1952 he again spent six months at Indiana University.

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ENDEAVOUR

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Science fiction

While popular exposition of the facts of science has achieved only a fluctuating and never very great following—though it is happily more fashionable now than it has been for a very long time—fiction with a scientific flavour has proved more acceptable and in recent years has gained a wide circle of readers. Indeed, in some countries science fiction seems to be displacing in popularity the crime story which has held first place for decades. On the generally acceptable premise that the public at large ought to know something of the progress of science and the part it may play in daily life, this development should meet with general approval, for as the sugared pill is the most palatable medium for medicine, so fact becomes more eagerly assimilated if attractively presented and seasoned with adventure, romance, and the other stock ingredients of fiction.

Fiction can undoubtedly be an important medium for the wide dissemination of scientific ideas. A necessary proviso, however, is that it should not only aspire to a reasonable literary standard but should be technically sound so far as matters of fact are concerned. Unhappily, it is very clear that, with a few praiseworthy exceptions, neither of these conditions is today being fulfilled or even sought. Much modern science fiction is badly written, inaccurate, and unbalanced in the sense of showing marked predilection for space travel; important and interesting though the latter may be, it is far from being the principal goal of modern science. It is clear that many authors and their publishers are profitably availing themselves of a change in public taste, without regard to—or probably consciousness of—the unfortunate consequences which may result.

Particularly unfortunate is the widespread introduction of what purports to be science into the very lowest forms of popular literature, where the twin themes of sex and violence have hitherto been deemed sufficient to satisfy the most demanding reader. Now, however, the vocabulary of science has been ransacked in an attempt to give an air of novelty to a well worn topic. The villain, who has always kept himself in the van of progress, now spurns even the most efficient of automatic weapons in favour of meson-guns; he maintains contact with his confederates by supersonic radio; and in his rare moments of relaxation dallies with his women in the comfortable shelter of a network of death-rays. There is, nevertheless, a crumb of

comfort to be gained even here, for the forces of good ultimately outwit those of evil by means of some even more dramatic application of pseudo-science.

Without attributing undue importance to it—and scientists as a class are perhaps inclined to take themselves over-seriously—the present situation ought not to be looked upon with indifference. At a time when research is inevitably being financed more and more from public funds it is correspondingly important to have the goodwill of the public itself. While it is axiomatic that no layman can have any profound knowledge of science as a whole, or even of any branch of it—in that he would then be considered to have graduated from the laity and entered the ranks of scientists—it is certainly desirable that he should not acquire a wholly false picture of scientists, their aims and ideals, and the results of their work. In one important respect bad science fiction can be very much more harmful than bad exposition of scientific fact: it deals with the scientist personally rather than professionally. To be constantly portrayed as curious in appearance and eccentric in habit, irresponsible in action and heartless in behaviour, and—in general—as belonging to a class apart, does nobody any good. Unless effectively countered by responsible writing, the sensational science fiction of today may have a cumulatively damaging effect upon public appreciation of both science and scientists.

Science, as it presents itself in its own journals, seems to be a wholly logical process, one experiment suggesting another and leading ultimately to a unifying explanation. Experience, however, shows that it is often the shot in the dark, the inspired guess confirmed later, that is of critical importance. Far from being the slave of fact and logic so often portrayed, the scientist profits greatly from a fertile imagination, and should be the last to deplore the same gift in the writer of fiction. Imaginative, yet informed, science fiction should be not merely tolerated but encouraged, for from it important ideas may stem. What is desirable, however, is that imagination should be restrained, and not applied in fields where fact is firmly established. Science fiction may well venture beyond the frontiers of knowledge, yet within those frontiers should acknowledge their existence.

Why, it may be asked, has science inspired so little literary work of real merit in spite of the

great popularity of science fiction in recent years? Clearly no single factor can be held responsible; nor can all the factors involved be discerned; nevertheless, it is possible to see some of the main reasons. Scientific and literary ability are both rare and are not commonly encountered in the same individual. On purely statistical grounds, therefore, one would anticipate that those equipped to write good science fiction would be few and far between, and experience certainly bears this out. Moreover, talent is not always exploited even where it exists; not unnaturally, scientists with a taste for writing often prefer to find their outlet in themes far removed from their daily work. It would be foolish to deprecate this preference, for it must surely seem desirable that the discipline of deductive reasoning—in which scientists, in their own estimation at least, are proficient—should be applied to as many fields of human endeavour as possible. The able professional writer finds plenty to occupy him without the trouble of acquiring a scientific education, to which, despite claims to the contrary, there is no short cut. The result is that there are few indeed in a position adequately to meet the demand, and so the field of science fiction has become largely the preserve of the ill-informed sensationalist.

Thus the problem of science fiction clearly lies not in the raw material—for the facts of science and their potential consequences rival the fantasies of fiction—but in the writers. Many scientists have shown considerable flair for explaining science to laymen, but have not ventured into the adjacent field of fiction, perhaps because the exposition of fact comes readily to them, whereas the recounting of fiction needs, apart from differences in technique, the suppression of certain professional inhibitions. Nevertheless, the step seems not to be a great one, and it is much to be hoped that, in the interests of both themselves and their profession, some scientists accustomed to explaining facts simply will try the experiment of doing so within a fictional framework.

Unfortunate though it is, the present situation is certainly not hopeless, for the works of such men as H. G. Wells and Jules Verne are proof that science and literature are not incompatible. While these were admittedly writers of an earlier generation, when science was much less complex than it is now, there seems no good reason why similar standards should not be attained today. Science in fiction generally depends upon principle rather than detail; although many new principles have been, and are constantly being, introduced, their

understanding and exposition need not be very difficult.

Science fiction if well done should benefit the cause of science as a whole, and while some attempts may prove a literary failure they are unlikely to do positive harm. The unqualified science writer is, however, a difficult problem. It would be both unjust and unreasonable to seek to discourage him, and to look upon all forms of science writing as strictly the preserve of scientists, for some of the best expositors of science today have had no formal training. The important thing is for the writer to know his limitations, to rely on himself only up to the limits of his own knowledge and thereafter to seek expert advice, which should not be withheld. This guiding principle is followed by the few, but there remain those who make no attempt to confine themselves to either truth or probability. With such there is no reasoning, and doubtless they will be always with us, but their numbers and influence can be limited by ensuring a satisfactory flow of better material. It is undeniable that there is a strong public appetite for science fiction, and if it cannot feed upon the good it will swallow the bad; only a sufficiency of good fare will make the other unpalatable.

Science has become an important—indeed, a dominant—factor in daily life, and a literature which either ignores it or grossly distorts it is clearly unbalanced, for the task of literature is to portray life in all its aspects. While it would be unfortunate if a sense of proportion were lost and writers cultivated science too intensively or too seriously, it is obviously desirable that the balance should be redressed. For this to be achieved, however, scientists must themselves take the lead, both by protesting against the misleading and sensational and by supporting the good. They have, too, an essential part to play by making themselves more accessible to the serious inquirer, and it will be a happy circumstance when the importance of this role is more widely recognized. In return for such assistance from scientists, however, writers must scrupulously respect the frequent professional need of the scientist for anonymity, and here the indiscretions of the few can be prejudicial to the many. Some recent novels, for example, have—despite a change of name—clearly identified particular laboratories, to the embarrassment and annoyance of those working in them. While such lapses of taste are fortunately rare, their occurrence is regrettable as being inimical to the establishment of good relations between scientists and writers.

High-voltage spark discharges

F. M. BRUCE

The development of high-voltage impulse generators and recording techniques has enabled investigations of the mechanism of the electric spark in air to be made in minute detail—in fact, to time-intervals of the order of a microsecond or even less. Spark theory has been advanced, and spark-gap characteristics have been studied as a method of measuring voltage and for elucidating the breakdown mechanism. For both purposes electrode profiles confining the gap to a region of uniform field strength are better than the familiar sphere gap.

SPARK DISCHARGES IN ELECTRICAL ENGINEERING

The sudden, and at times spectacular, appearance of an electric spark in the air gap between two electrodes was familiar to scientists for many years before the physical nature of the phenomenon could be investigated or to any extent understood. Spark discharges could be obtained from Leyden jars, from Wimshurst machines, and from induction coils. Similarities between lightning discharges and the electric sparks from Leyden jars led Franklin in 1752 to make the famous experiment [1] that proved the relationship. His experiments led him to the successful application of the principles of protection by earthed conductors, but this empirical work preceded relevant theoretical knowledge by more than 150 years.

At the beginning of the present century, electrical engineers used the transformer to develop systems for the transmission of electrical energy at high A.C. voltages. For any given transmission system there is a preferred voltage, which is determined by the energy to be transmitted, the distances involved, and economic considerations [2]. The ever growing demand for electrical energy led to an increase in operating voltages up to the present level of 380 kV; much higher voltages became available for research and test purposes. Testing-transformers, connected in cascade, have made available voltages of 1000 kV and more at power frequencies, but it is also necessary to test high-voltage equipment under conditions representing the over-voltages due to lightning disturbances on lines and connected equipment. Impulse generators [3], comprising a number of capacitors charged in parallel and discharged in series, are used to simulate travelling-wave phenomena, the resistance-capacitance network of the output circuit being adjusted to give a unidirectional waveform with a steep wavefront rising to the crest value, and a slower rate of voltage decay on the tail.

Such waves are defined by two time-intervals T_1 and T_2 , in units of microseconds, where T_1 is the time to reach the crest value, and T_2 the time for the voltage to fall to half the crest value on the tail. A knowledge of the characteristics of those waveforms that would represent service conditions, and of those obtained in the laboratory, had to await the development of high speed, single-stroke oscillograph techniques [4]; then waves in which $T_1/T_2 = 1/5$ and $1/50$ were standardized for test purposes—although many other waveforms are necessarily used in research work.

When an impulse voltage is applied to an insulating medium, breakdown or spark-over may occur on the front, crest, or tail of the wave, according to the magnitude and shape of the wave and the characteristics of the insulation. For a given set of conditions, there is thus a time-to-breakdown, and the variation of this time with the magnitude of the voltage for each class of insulation in a transmission system is of great importance in the design of the equipment. The insulation of a system must be so co-ordinated that, in the event of a lightning disturbance, the protective gaps will flash over before dangerous voltages are reached on the equipment at the ends of the line. Thus, if the curves I-III of figure 1 represent the characteristics of the solid insulation, bushings, and protective rod gaps respectively, a high overvoltage rising within the time-interval A

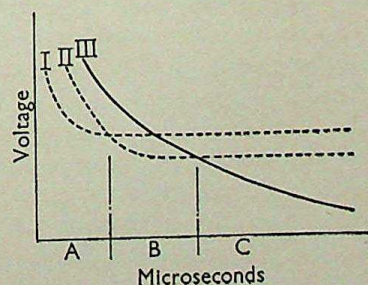


FIGURE 1 — Voltage-time curves.

would cause breakdown of the solid insulation; within the time B it would cause bushing flashover; and only when the voltage rose to a dangerous level at times within the region C would the rod gap afford the desired protection. It is necessary that the voltage-time characteristics for protective devices should lie wholly below those for the insulation of the system if complete protection is to be achieved.

Electrical engineers have many problems of insulation for high alternating and impulse voltages that require a knowledge of how breakdown occurs through the air, as in the case of a protective gap. The wide variations that can occur in atmospheric conditions have to be considered, not only as affecting an air gap, but also with regard to their influence on the flashover of exposed insulator surfaces. In addition, a flashover due to lightning disturbances on an energized system can provide a path for power current, leading to the formation of an arc carrying the full short-circuit current of the system. Less obvious than conventional insulators, but of increasing importance as insulating media, are vacuum and high-pressure gas, and high D.C. voltages may become more widely used. There, too, an understanding of the mechanism of breakdown or spark-over is essential for satisfactory design of equipment.

VOLTAGE MEASUREMENT BY MEANS OF SPARK-GAPS

The measurement of high voltages in terms of the maximum length of spark that could be produced between two given electrodes in air was, for a time, the only method available—there was no theory or independent method of measurement to provide a check. The pioneer work of Townsend in formulating a physical theory for the mechanism of the spark initiated theoretical and experimental work that is continuing today [5]. Observations on the breakdown of atmospheric gaps under impulse-voltage conditions, and the development of high-speed oscillography and photographic recording, appeared to challenge the validity of the secondary ionization processes postulated by Townsend, as they were then understood. If the voltage across a gap is raised above the static sparking potential V_s to a value $(V_s + V)$ there is a measurable time-lag before breakdown occurs. This time-lag can be divided into two intervals, the statistical lag T_s , which is the time required for the appearance of an electron favourably placed to initiate primary ionization by an electron avalanche, and the formative lag T_F , which is the further time required for the breakdown

mechanism to develop [6]. T_s can be controlled by suitable irradiation of the gap, but T_F remains as a characteristic of the physical processes involved in the breakdown mechanism. It was found that, provided the overvoltage V was sufficiently great, there was apparently no lower limit to the value of T_F , and values were obtained that were less than the transit times of positive ions crossing the gap to produce secondary ionization. Attention was thus focused on the nature of the secondary processes [6] involved, and measurements of the pre-breakdown current (I) did not reveal the up-curving of $\log I$ as a function of the spacing (d) required by Townsend's theory. A streamer theory of breakdown was accordingly advocated [6], based upon positive-ion space-charge and photo-ionization of the gas. This was claimed to be independent of the cathode and to account for very small values of T_F . But the theory of photo-ionization was qualitative only, and, what was still more significant, the Townsend mechanism was admitted for values of pd less than about 200, where p is the gas pressure in mm of mercury and d the gap spacing in cm. The apparent change in the mechanism at a critical value or range of pd indicated most clearly the need to explore this range experimentally.

Investigations carried out by the research group working with F. Llewellyn-Jones at Swansea [5] have revealed the deficiencies of the streamer theory, and have restored the Townsend mechanism to favour with both theoretical and experimental evidence, including explanation of small values of T_F . The success of the investigations was made possible by improved methods of measurement and stability, and by the correct design of the experiments [7], in which respect by itself the work is of very great interest.

If to the physicist the spark-gap was an object for study as a source of experimental data, to the engineer it remained as a specified standard for high-voltage measurement, and many calibrations for this purpose were made in engineering laboratories. This work also assisted in an appreciation of the practical problems of flash-over between electrodes of more complicated geometrical form than simple spheres. With each advance in the precision with which high alternating and impulse voltages could be controlled and measured, new data were obtained on the characteristics of spark-gaps [8], which had to be explained by the physicist and applied by the engineer to other problems of design; at the present time the interests of one can hardly be separated from those of the other.

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As a voltmeter, the customary spark-gap consists of two equal spheres at a distance from one another not greater than their radius. At wider spacings the field becomes markedly non-uniform until, eventually, a corona discharge at the surface of the spheres precedes breakdown. In most cases, the gaps are used asymmetrically, the high voltage being applied to one sphere while the other is connected to earth. Variations were found in the calibration data obtained in different laboratories for these gaps. This was largely due to the asymmetry, and to the presence of earthed objects and of the building itself, which gave a higher gradient at the surface of the high-tension sphere [9]. Since the most favourable position for an electron to initiate an avalanche is in the vicinity of the cathode, the effect of asymmetry would be to give a lower breakdown voltage when the high voltage sphere was negative. Polarity indicators were therefore used to determine the polarity of the high-voltage sphere at the instant of breakdown with alternating voltages [10]. For spacings less than the radius of the spheres the field is not greatly affected by asymmetry, and flashover is independent of polarity. As the spacing is increased, the proportion of breakdowns during the negative half-cycle increases until it becomes 100 per cent. At still greater spacings the field between the spheres is more divergent, corona discharges can form at the surfaces owing to the high gradients there, and conditions close to the anode then determine events, so that breakdown occurs in the positive half-cycle [8]. Similar polarity characteristics would be expected when comparing calibration curves for positive and negative voltages, whether D.C. or impulse, and a correlation has been found between the A.C. and impulse calibrations [11].

The calibration and use of sphere gaps for high-voltage measurements were examined in detail; it became the practice to make a series of breakdown measurements at regular intervals and to plot a sequence diagram. It was not unusual to find, in a sequence, low freak values which could be explained as due to fortuitous circumstances such as the presence of dust particles, but high freak values were not observed. Surface effects were considered [12], and it was recommended that a number of conditioning breakdowns should precede those used for measurement, as even with a current-limiting resistance a film of tarnish forms on the surface of the sphere. As an aid to consistency, especially at small spacings, it was recommended that the gap should be irradiated from an external source.

Further difficulties were experienced in the use of sphere gaps for impulse voltage measurement. The effects of waveform were eliminated by making calibrations for specific limits to the wave-shape [12], but owing to the statistical spread of values of time-to-breakdown it was found that there was a range of voltage within which the frequency of breakdown varied from zero to 100 per cent for a number of successive applications of voltage. The breakdown voltage for a given gap was therefore defined as that voltage which produced spark-over on 50 per cent of the impulses.

THE UNIFORM-FIELD SPARK-GAP

Many difficulties inherent in the use of spherical electrodes for spark-gaps would be overcome if the path of the spark lay wholly within a region of uniform field strength. The fact that the field was uniform would dispose of the problems arising from asymmetry, and ion movement would not be influenced by longitudinal variations in the applied field. Such a field exists between infinite parallel planes, but for practical use the boundary effects have to be considered. In 1923, Rogowski [13] proposed an electrode contour conforming to an equipotential surface at the boundary of parallel planes, and such that the gradient on the curved edges was everywhere less than between the parallel surfaces. At that time, high alternating voltages could not be stabilized or measured very accurately, nor was there the empirical knowledge of spark phenomena that had accumulated some ten years later. In 1933, Stephenson [14] proposed a contour for uniform-field electrodes based upon studies of corona discharges, and preliminary observations indicated that this contour gave the desired characteristics; the spark-over voltage V could be defined by the equation

$$V = AS + B\sqrt{S},$$

where A and B are constants and S is the electrode separation. The writer and his colleagues subsequently undertook the calibration of these gaps for high alternating voltages [15]. The electrodes have a central plane area surrounded by curved edges, and must be mounted with the planes parallel to each other. At spacings up to a maximum, which is of the order of the diameter of the plane areas, sparking takes place in the region of uniform field; beyond this maximum the spark paths lie between the edges of the electrodes. These electrodes are made of a size appropriate to the maximum voltage that is to be measured. Three sizes were calibrated, and possible sources

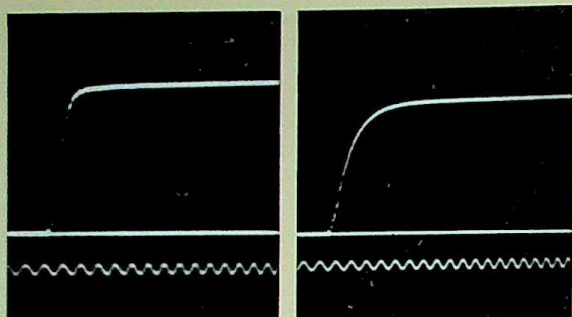


FIGURE 2 - 0.17 and 0.7 μ sec wavefronts. 5 Mc/s timing waves.

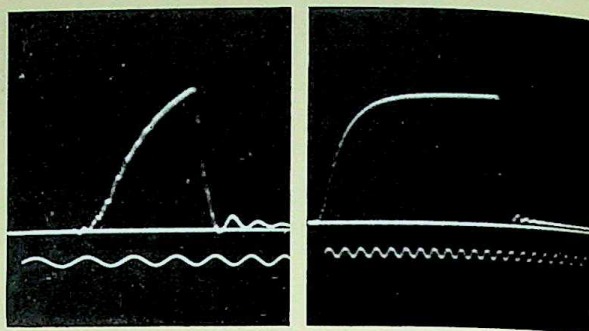


FIGURE 3 - Records of breakdown on wavefront and wave-tail. 5 Mc/s timing waves.

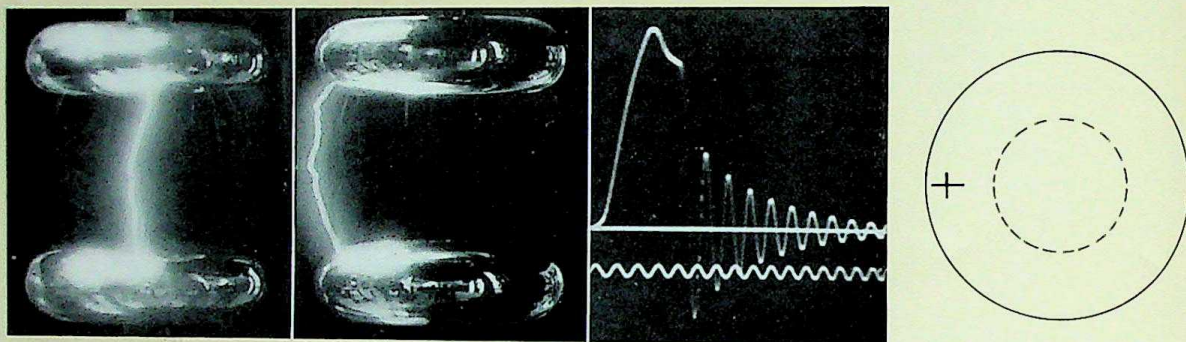


FIGURE 4 - Main and suppressed discharges in non-uniform field. 8.7 cm spacing, upper electrode positive.

In figures 4-10 the diagram shows the location of the spark roots.

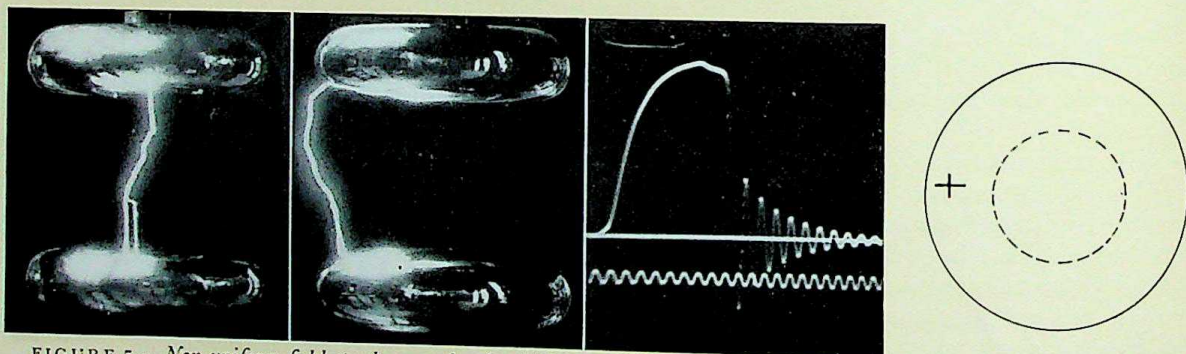


FIGURE 5 - Non-uniform-field spark-over, showing bifurcation. 8.7 cm spacing. No filter. Upper electrode positive.

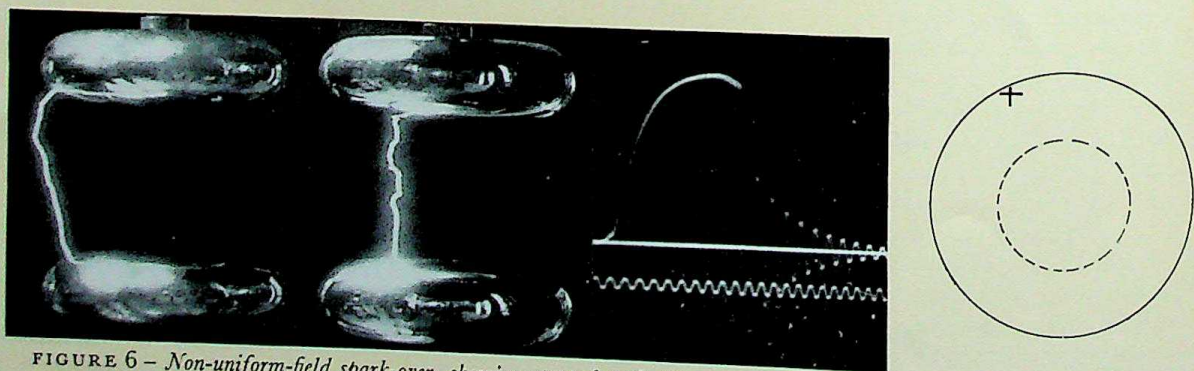


FIGURE 6 - Non-uniform-field spark-over, showing stepped path. 8.7 cm spacing. No filter. Upper electrode positive.

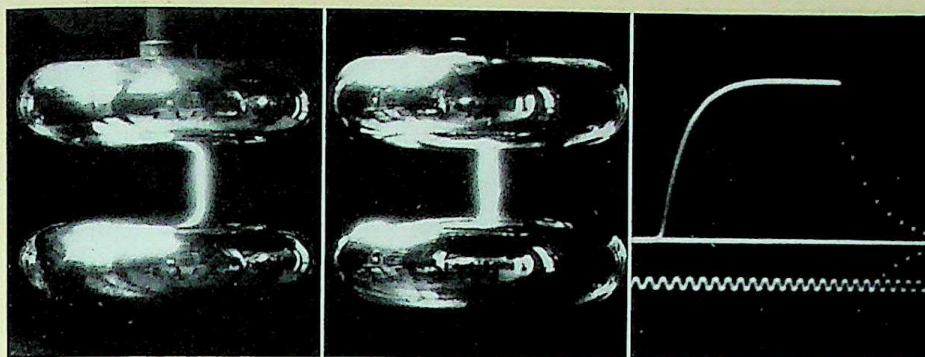
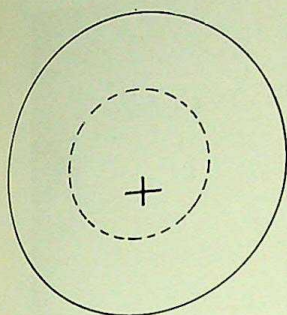


FIGURE 7 - Uniform-field spark-over. 2.9 cm spacing. No filter. Upper electrode positive.

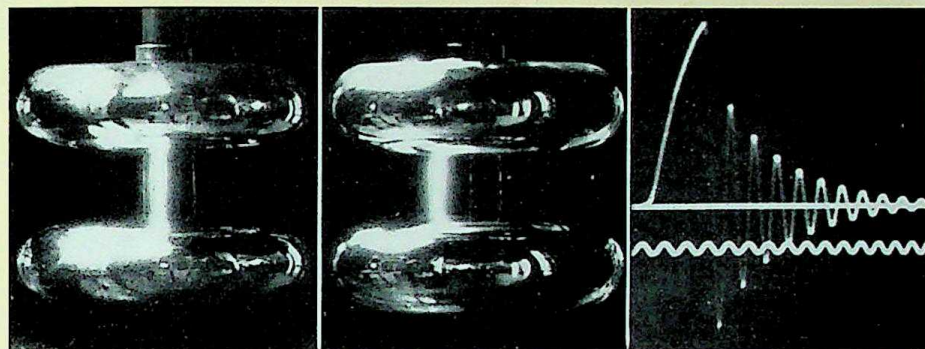
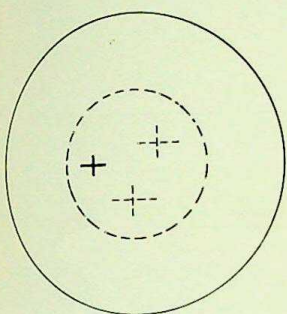


FIGURE 8 - Uniform-field spark-over, showing suppressed discharges. 2.9 cm spacing. No filter. Upper electrode positive.

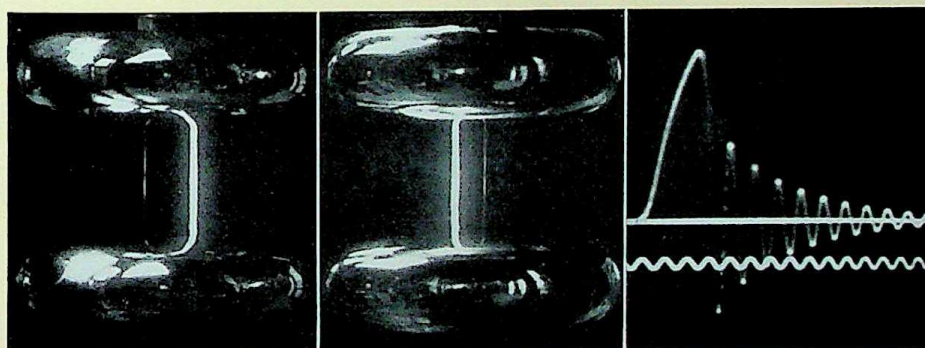
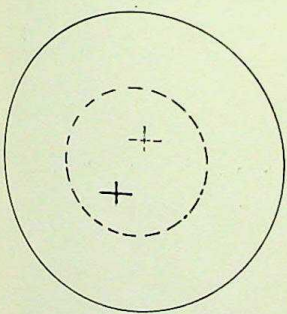


FIGURE 9 - Uniform-field spark-over, showing suppressed discharge. 6 cm spacing. No filter. Upper electrode positive.

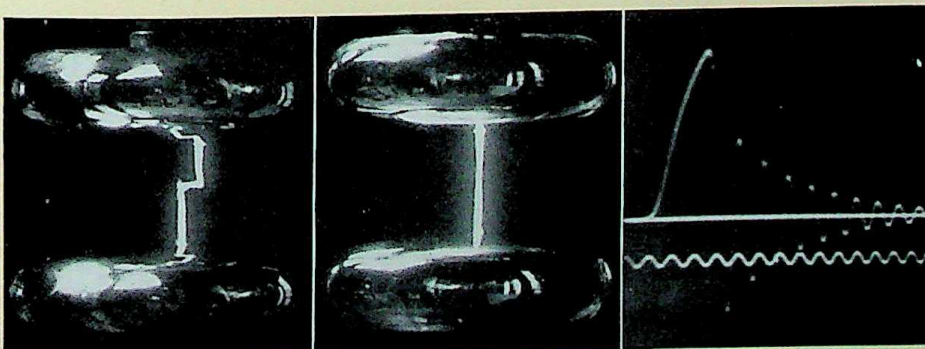
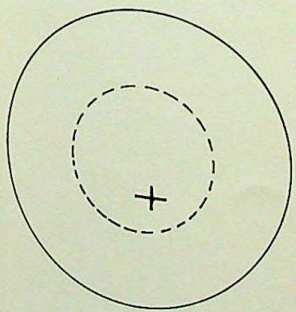
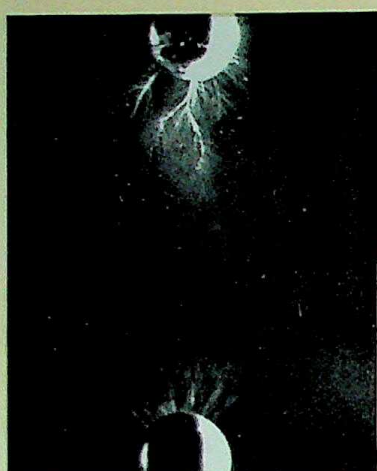
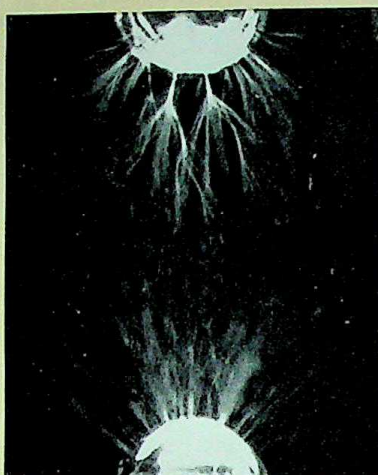


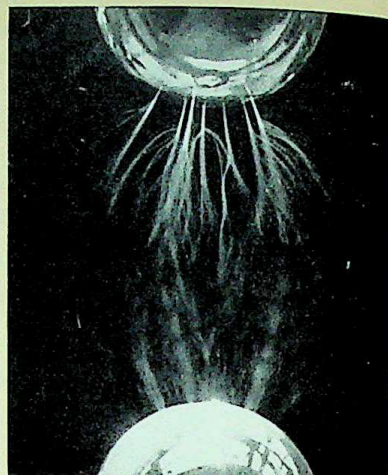
FIGURE 10 - Uniform-field spark-over, showing stepped path. 6 cm spacing. No filter. Upper electrode positive.



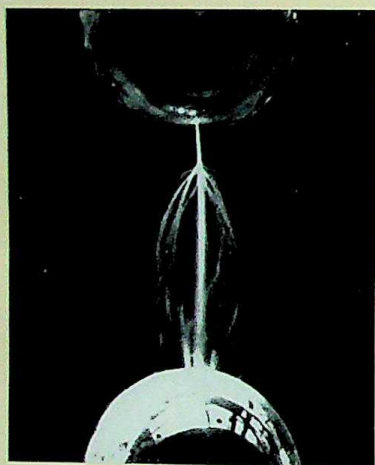
6.25 cm spheres; 25 cm spacing.



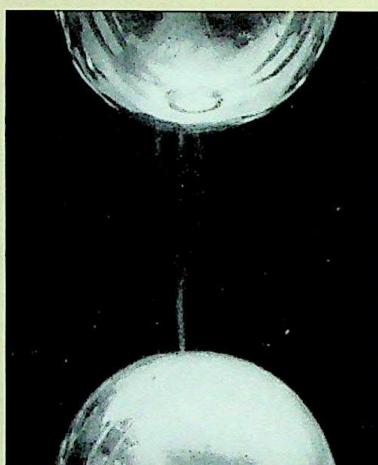
6.25 cm spheres; 12.5 cm spacing.



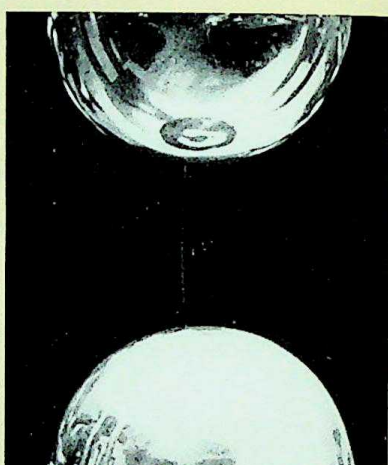
12.5 cm spheres; 15 cm spacing.



12.5 cm spheres; 12.5 cm spacing.



12.5 cm spheres; 9.0 cm spacing.



12.5 cm spheres; 6.25 cm spacing.

FIGURE 11 - Suppressed discharges in air gaps. In all except the last two illustrations the upper sphere is positive.

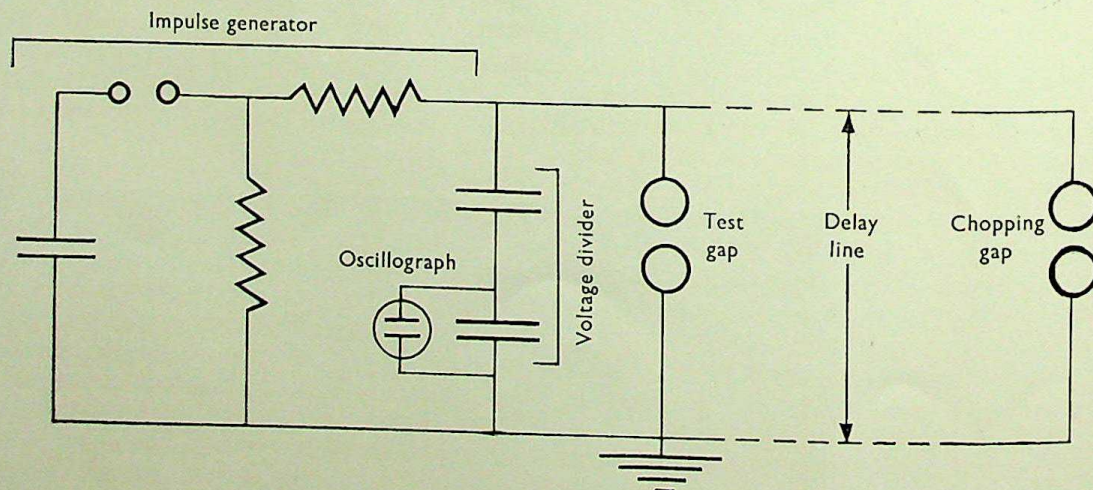


FIGURE 12 - Circuit for producing suppressed discharges.

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of error due to adjustment or proximity effects were investigated. Similar investigations were carried out with spheres of 25 cm diameter to provide a comparison and a link with other work on sphere gaps. In order to assess the significance of the small variations in breakdown voltage that were experienced in some of these tests, a considerable time was spent in developing and checking the accuracy of the peak voltmeter used as a reference, and the accuracy finally achieved was of the order of ± 0.03 per cent.

It was found that, for all sizes of electrode within their respective ranges of spacing, the spark-over voltage (in peak kV) was given by

$$V = 24.2S + 6.08_2 \sqrt{S}$$

at 20° C and 760 mm Hg, where S was the spacing in cm. The departure of individual values from this equation was less than 0.2 per cent, and the average value of the mean deviations for the sequence diagrams was 0.06 per cent. The spark-over was independent of polarity, and the spark paths were uniformly distributed over the plane areas. This latter characteristic is a valuable indication that the flatness of the surfaces and the accuracy with which they are made parallel give sufficient uniformity of field. Since each spark path lies between different points on the electrode surfaces, there should not be any marked conditioning effect. This was confirmed by a series of polarity tests on newly cleaned electrodes and spheres, though low break values that can be attributed to particles of dust may and do occur. Owing to the guard-ring action of the edges in screening the region of uniform field, proximity effects are much less than for the corresponding sphere gap, even at the maximum spacings.

The above results indicate that the uniform-field gap should be much more suitable than the sphere gap for impulse voltage measurement, and, for similar reasons, that it would be the better form of gap with which to study the mechanism of breakdowns. It does not exhibit a polarity effect, and the substantial volume of uniform field within which the spark can develop increases the probability that an electron will be favourably placed to initiate breakdown. This opinion was confirmed by some observations on the measurement of recurrent negative pulses [16].

With the provision of facilities for high-voltage investigations at the Royal Technical College, Glasgow, the writer was able to initiate a number of investigations on spark characteristics, making use of the special advantages offered by the uni-

form-field gaps for such work. The major points of interest were reported in 1951 [8], and subsequent progress is described below.

INVESTIGATIONS IN PROGRESS

A necessary preliminary to spark investigations is the provision of sources of stable voltage and independent methods of accurate voltage measurement. These have been developed during the last two years. For alternating voltages, an automatic controller of frequency and voltage was produced for the machines supplying the transformer [17]. All these features are important in obtaining good accuracy from the peak voltmeter, the performance of which is being investigated in considerable detail. The main problem in impulse voltage measurement lies in the voltage divider that must be used in conjunction with an oscillograph, and the problem is made more difficult when reliable measurements are required on very steep wavefronts. As in most other high-voltage laboratories, this matter has been under investigation at Glasgow in recent years, and continues to be so. A normal type of impulse plant is available for work with standard waveshapes, but waves with steep fronts and long tails are necessary for a study of spark mechanisms; for this work, impulse generators for voltages up to some hundreds of kV have been built. As much of the work is statistical, it is important that the generator output should, when desired, be constant on successive discharges, and this necessitates a stable charging voltage and accurate measurement of it. These remarks on equipment and techniques are mentioned to illustrate that the investigations now in progress aim at a higher order of accuracy than is usually obtained in such work. The development of suitable methods is not yet complete, but enough has been done to enable a preliminary survey of the scope of each investigation to be made, and to assess the suitability of the techniques developed.

EFFECT OF IRRADIATION ON IMPULSE BREAKDOWN

This work uses an impulse generator with a maximum output voltage of 100 kV, so that the dimensions of the gaps and supporting structures can be kept small enough for complete screening to be effected. The waveshapes used so far are 0.17/250 and 0.7/250, as shown in figure 2. Typical records of wavefront and wavetail breakdown are reproduced in figure 3. For sphere gaps, transition curves have been reported [18] from zero to 100 per cent breakdowns under various

conditions of irradiation, and the work is now being extended to uniform-field gaps, a variety of waveforms, and spark-over on the wavefronts. Simultaneous measurements are also being taken with spherical electrodes 6.25 cm in diameter.

In the condition described as non-irradiated, the gap is completely shielded by a pressboard box of adequate dimensions. Light from the generator gaps is used for ultraviolet irradiation, and the equivalent of 0.5 mg of radium is inserted below the surface of one electrode for radium irradiation. The relative effects of these conditions have been determined by the transition curves shown in figures 13-16, the gap spacing being about 2 cm in all cases. The voltage range ΔV for a transition from zero to 100 per cent breakdown is plotted as a percentage of the voltage for zero breakdown. With non-irradiated gaps (figures 13 and 14), ΔV for the uniform-field gap is much less than for the sphere gap, and is not greatly affected by polarity or wavefront changes. With irradiation, the curves are drawn for 0.17 and 0.7 microsecond wavefronts (figures 15 and 16) respectively. In the case of the uniform-field gap, one curve could serve for all combinations of irradiation, polarity, and wavefront, but for the sphere gap the ultraviolet irradiation has been less effective than radium in reducing ΔV , especially with the longer wavefront. The results from all four figures confirm the advantages that were expected from using uniform-field gaps under these conditions. For practical purposes the spark-over voltage is defined as that giving 50 per cent breakdowns, and as a means of comparing the different characteristics it is suggested that the slope of the curve at 50 per cent breakdown could be regarded as a figure of merit. This has been expressed as the value of ΔV per cent for 0-100 per cent transition as given by the tangent to the curves at 50 per cent. The results are given in the accompanying table.

From oscillograms taken during the above tests and with overvoltages, the

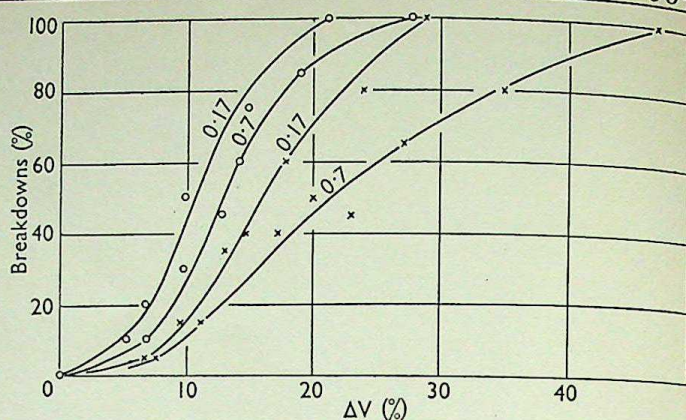


FIGURE 13 - 6.25 cm spheres, non-irradiated, 0.17 and 0.7 μ sec wavefronts. o = positive waves; x = negative waves.

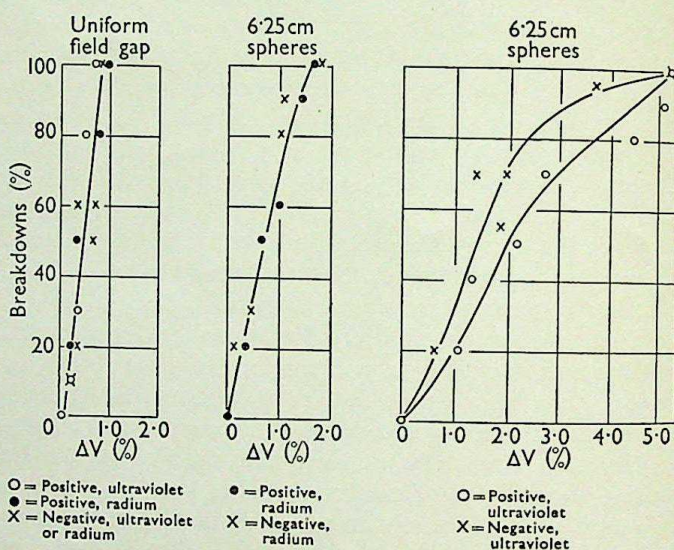


FIGURE 16 - Curves for 0.7 μ sec wavefront.

TABLE

Figure of merit for the particular spark-gaps investigated

Irradiation	6.25 cm spheres				140 kV uniform-field electrodes			
	Positive		Negative		Positive		Negative	
	Wavefront				Wavefront			
	0.17	0.7	0.17	0.7	0.17	0.7	0.17	0.7
None ..	21.0	27.0	28.0	46.0	8.8	9.8	11.0	13.0
Ultraviolet ..	2.8	5.2	2.8	5.2	0.8	0.7	0.6	0.8
Radium ..	1.6	1.6	1.5	1.7	0.8	0.9	0.8	0.8

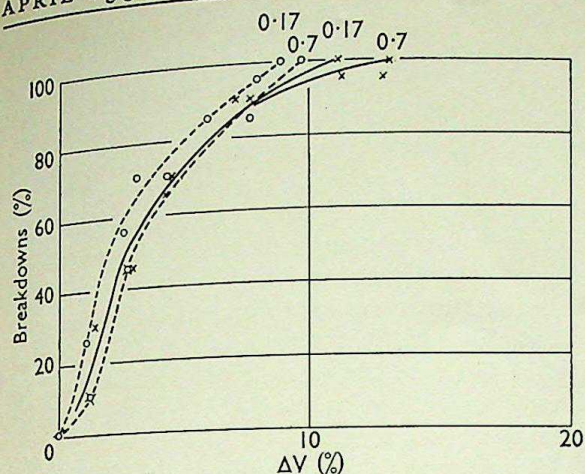


FIGURE 14 - Uniform-field gap, non-irradiated. $\circ$ = positive waves; $\times$ = negative waves.

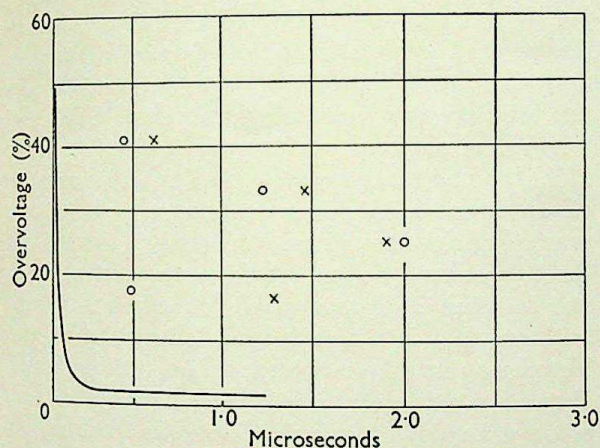


FIGURE 17 - 6.25 cm spheres, time-lag for $0.17 \mu\text{sec}$ waveform. Curve = irradiated gap, $\pm$ waves; $\circ, \times$ = non-irradiated gap, $\pm$ waves.

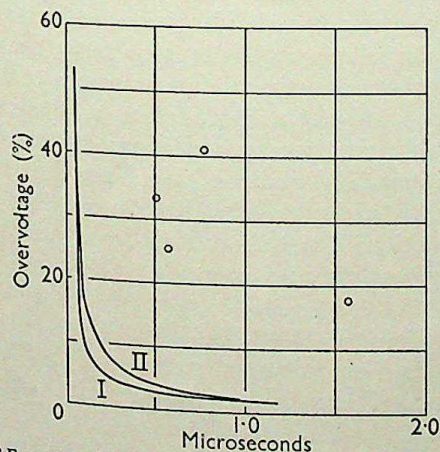


FIGURE 19 - 6.25 cm spheres, time-lags for $0.7 \mu\text{sec}$ waveform. I = Radium, $\pm$ waves; II = ultraviolet, $\pm$ waves; $\circ$ = non-irradiated, positive.

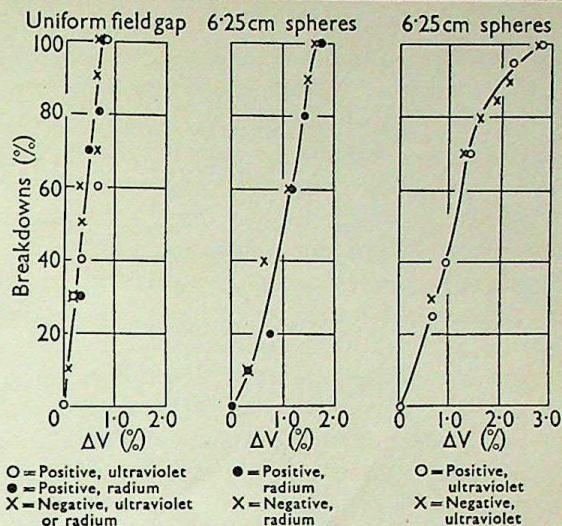


FIGURE 15 - Curves for $0.17 \mu\text{sec}$ waveform.

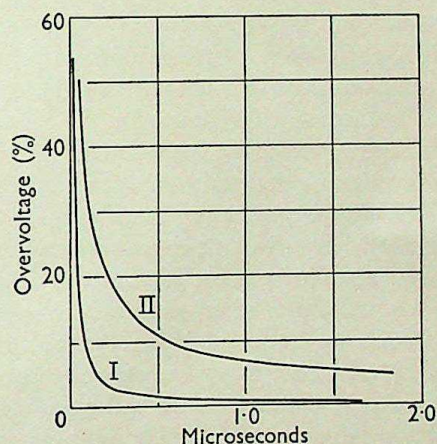


FIGURE 18 - Uniform-field gap, time-lags for $0.17 \mu\text{sec}$ waveform. I = Radium or ultraviolet irradiation, $\pm$ waves; II = non-irradiated.

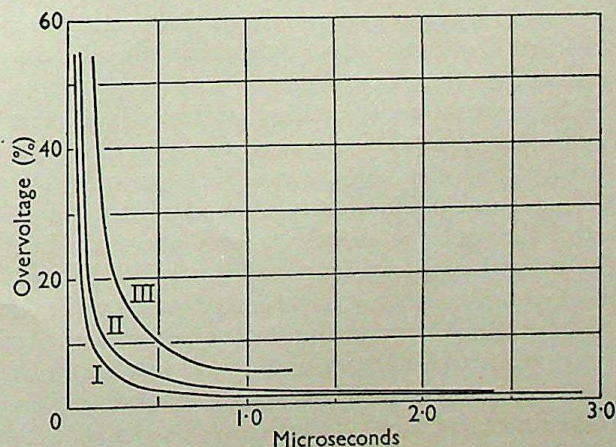


FIGURE 20 - Uniform-field gap, time-lags for $0.7 \mu\text{sec}$ waveform. I = ultraviolet, $\pm$ waves; II = radium, $\pm$ waves; III = non-irradiated, $\pm$ waves.

time-lag to breakdown has been measured as the time from the instant at which the voltage reached the peak value of the alternating breakdown voltage for the gap in question, to that at which breakdown occurred. The overvoltage is given as the percentage by which the peak value of the impulse applied exceeds that for zero breakdown on the ΔV curves. The mean values gave surprisingly smooth curves, as shown in figures 17-20, except for the non-irradiated sphere gap, which gives scattered points. It is again demonstrated that the uniform-field gap, without irradiation, gives a relatively stable performance. For investigating the spark mechanism, attention will have to be concentrated on the characteristic at very small overvoltages, for which purpose the accurate control of the impulse generator output is essential; D.C. voltages may be used also.

PHOTOGRAPHY OF SPARK CHANNELS

For investigations of the transition from uniform to non-uniform breakdown, as the spacing between uniform-field electrodes is increased beyond the maximum spacing of their range, it is important to know the exact location of the spark path. This can be done by photographs taken simultaneously from two directions perpendicular to one another; the location of the spark roots can then be plotted on a plan of the electrodes. By means of mirrors, such dual photographs can be obtained side by side using only a single camera.

Uniform-field electrodes for voltages up to a peak of 140 kV were found to have a maximum spacing for uniform-field breakdown lying between the values of 6.2 and 7.2 cm [15]. These electrodes were set up for uniform-field breakdown when irradiated by light from the impulse-generator trigger gaps, and the ΔV curve was checked for conformity with those already described. For the first series of photographs, 1/50 positive waves were applied, with 50 per cent overvoltage, to a gap spaced at 8.7 cm to give non-uniform field breakdown. A filter was used to reduce halation when the main spark-channel alone was to be recorded, but was removed when suppressed discharges were to be examined. Complete screening from the generator gaps is difficult with this larger equipment, but some photographs were taken with screening limited to a sheet of pressboard between the gap and the generator. The results are shown in figures 4-6, together with the corresponding oscillograms. Figure 4 shows a large number of discharges occurring in the non-uniform field and suppressed by the development

of the main spark. The channels are most strongly marked near the positive electrode, and show branching. A similar record (figure 5) shows a prominent bifurcation in the main spark channel; suppressed discharges, if present, are very faint in this instance, although there was no screening in either case. With the screen in position, a discharge with pronounced steps was recorded (figure 6), although this may not be specifically associated with the screening. In all three cases, the oscillogram shows pronounced distortion just before the breakdown; this phenomenon will be investigated in conjunction with records of the gap current in future work.

Figures 7 and 8 show uniform-field breakdown for a spacing of 2.9 cm, with the screen in position. Breakdown on the tail in figure 7 shows an almost straight path, the apparent curvature at the ends resulting from reflection in the electrode surfaces. When an overvoltage is applied to obtain breakdown on the wavefront, suppressed discharges appear (figure 8), but all the discharge paths are straight and within the uniform field. At a spacing of 6 cm, uniform-field breakdown is still obtained, and figures 9 and 10 show records of wavefront breakdown. In figure 9 the screen was in position, and one prominent suppressed discharge can be seen. An interesting feature is the increase in intensity of this channel in the mid-gap region, which is revealed in both views. Figure 10 was taken with the screen removed, and shows a striking step in the spark channel. This was not a unique example of a step in the uniform-field breakdown, and the matter will be investigated further. Up to the present, these steps have been found when the screen was removed. Since the field is uniform, there is no reason why the electron avalanches should originate from any one particular plane, and the step may be due to bridging between two avalanche tracks, one beginning from mid-gap and one from near the cathode.

The fact that, under conditions of overvoltage, the uniform-field gap can have a number of spark channels developing simultaneously, is again a confirmation of the short time-lags and the consistency that may be expected.

SUPPRESSED DISCHARGES

Another programme mentioned earlier [8], from which results have now been obtained, derives from Torok's technique of suppressing discharges after a certain time, either by reflections in a short-circuiting loop connected across the gap, or by chopping with a second gap in

parallel [19]. In the present work it was decided to combine the two techniques to find if an easier control could thus be gained, and present indications are that this has been achieved. The circuit used is shown in figure 12. A selection from the first series of photographs taken in the preliminary work is reproduced in figure 11, and, reading from left to right along the two lines, the photographs show an approach in successive stages to a uniform field using spherical electrodes. For the last two records, the polarity of the impulses applied to the upper sphere was changed to negative, and a comparison with the previous photographs shows that the structure of the discharge is determined by polarity and not by asymmetry. In all cases, high overvoltages of about 600 kV were applied, with the chopping gap set to flash over at 300 kV, falling to 200 kV as the spacings were reduced. Similar records have not yet been obtained for a uniform-field gap.

There is great similarity between the discharge structures at the positive and negative electrodes and Lichtenberg figures of corresponding polarity, and probably the two phenomena are to be explained on similar lines. In the vicinity of the cathode, electron avalanches diverge into a region of lower field strength. At the anode, in the region of maximum field strength, electrons are swept in from the air, leaving a positive space-charge to which electrons arriving from mid-gap will be attracted and so drawn into the same channel. The second and third photographs suggest that the branching occurs at a distance from the surface of the anode which varies with the surface gradient at that point. The fourth photograph shows a single channel across a gap-spacing that is approved for impulse voltage measurement [12], but, like the

others, it is diffuse towards the cathode. All the gaps shown were irradiated to an indeterminate extent by the trigger gaps of the impulse generator.

Contemporary work by Norinder and Salka, and by Pucher [20], with sphere-plane gaps, gives similar results in the vicinity of a positive sphere; with a quartz lens, these workers find a very strong intensity at the ends of the channel.

CONCLUSION

From the above work and allied investigations, it will soon be possible to give a second calibration of the uniform-field gap for high alternating voltages, and a calibration for impulse voltages under specified conditions. These calibrations provide a datum from which variations can be judged, and the whole should make a useful contribution to spark theory. Other investigations will show how the Townsend mechanism functions in highly divergent fields, for the suppressed-discharge technique will be extended to the case of a positive point discharge.

In the limiting case of long sparks, the lightning discharge, it is known that the leader stroke advances in a series of current pulses or steps which successively increase in length. One theory to account for this [21] is based on a glow-to-arc discharge transition; it may be possible by the suppressed discharge technique to find evidence concerning this question, if an arc column is found to exist at the anode of a divergent field before breakdown is complete.

ACKNOWLEDGMENTS

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The Bermuda Islands

T. A. and ANNE STEPHENSON

The Bermuda Islands, separated by nearly 600 miles of ocean from the nearest land, and surrounded by warm water in the fringe of the Sargasso Sea and within reach of the Gulf Stream, offer great attractions to biologists who wish to study the fauna and flora of oceanic islands. Professor Stephenson and his wife have recently made such a study, and here describe some of their observations. The rocky reefs around Bermuda present features of much interest.

The Bermuda archipelago (figure 1), while including many individual islands, is very compact. Most of the islands are small; only five of them are of any considerable size, and these are linked by bridges. The larger ones consist of low hills, and much of the coastline is steep or precipitous. Because of the oceanic position, the most exposed coasts of the islands, and the surrounding reefs, are subject to very powerful wave-action from the enormous Atlantic swells; this is so persistent that in the most wave-washed places there is only a limited number of days in the year when it is possible to land and work on them. The islands are situated on the top of a submarine mountain and are surrounded, below the water, by sand-covered banks from which arise hundreds of rocky reefs. These reefs not only have a definite arrangement in relation to the islands, but show peculiarities of structure which place them among the most interesting products of combined organic and inorganic activity to be found in the world.

The islands have a considerable human population, varying in colour from black to white, and a flourishing tourist trade, especially from America. There are two towns, Hamilton and St George's. Near the latter is situated the Bermuda Biological Station, where, with the assistance of the Royal Society and the American Philosophical Society, we were able to spend three months in the summer of 1952. The land-vegetation of the islands is of a typically subtropical nature. Bananas are grown, and hibiscus (figure 14), oleander, frangipani, bougainvillea, and various other flowering trees flourish. Many of these have been imported for garden purposes.

A recent development of plant and animal geography has been an attempt to correlate the distribution of water-masses of different temperatures over the face of the Earth with the distribution of populations of plants and animals. The dependence of marine organisms upon a certain

temperature-range for their very life, and their great sensitivity to it in their distribution, have been emphasized in many different ways. One of the striking examples was provided by Bermuda itself in 1901, when a spell of unusually cold weather early in the year resulted in the death from cold (but at temperatures well above zero) of large quantities of the warm-water fish which live around the islands, as well as of corals and other invertebrates. The Bermudian waters can by no means be classified as tropical, and although the term subtropical may suitably be applied to them, they have the peculiarity that in the summers they are almost as warm as those in some marginal tropical areas, such as the Florida Keys. On the other hand, in the winters they are decidedly cooler than those in any tropical region, and even cooler than those in some other subtropical ones. Consequently, many warm-water species which inhabit the Bermudian seas are living, in winter, at temperatures fairly close to the lower limit which they can tolerate, so that a cold spell such as that of 1901 can cause extensive devastation. An interesting question is whether the annual cycle of temperature at the Bermudas is warm enough to permit the growth of coral-reefs, and with this we shall now deal.

Rocky reefs arising from the sea-floor can be of several types. Many of them are merely outcrops of whatever rock is characteristic of the region in which they are found. Others are built up entirely of the skeletons of living plants and animals; the largest and most impressive of these are found only in shallow tropical seas and are known as coral-reefs. These reefs do not necessarily contain any material whatever of geological origin; the whole rock of which they consist is derived from the skeletons of organisms, primarily corals and calcareous algae. The reefs about Bermuda are particularly interesting because they seem to be intermediate between the two types just described.

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While they are of every imaginable shape, they belong roughly to two varieties. In one form the reef is wholly submerged, so that the top of it never emerges from the sea and is not even awash at the lowest tides, though often very near the surface. These reefs are irregular in shape and very variable in size and in the height to which they rise above the surrounding sea-floor, but they are often very sharply delimited and commonly have precipitous and overhanging sides. Over their surfaces grow corals in moderate numbers, and groves of those supple and perpetually waving alcyonarians known as gorgonians. The prevailing colours are brown, purple, and yellow, with every possible shade and gradation of these tints; the effect is very beautiful. In the waters swim tropical fish in profusion, of every shape and colour. In some places there is a direct transition from the coastal rocks to reefs of this type. The reefs of the second variety, which are locally called boilers, are most peculiar structures. Their highest parts reach the surface of the sea and are awash or project a little above sea-level at low tide, but in ordinary weather the surf boils over and around many of them so heavily that it is impossible to keep a footing on them. By choosing one's day, however, it is feasible to explore them, though even then the emergent tops are often sufficiently washed to be permanently wet. Many of them have the shape of a funnel with a thick stem (figure 11). From the stem the reef expands to its overhanging margin, which

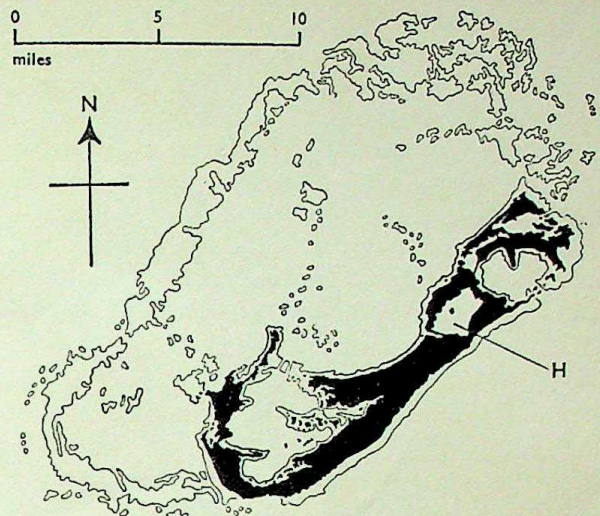


FIGURE 1 - The Bermuda Islands. Land is shown in black, and the main sand-banks from which the reefs arise are indicated in outline. H, Harrington Sound.

forms a raised rim round its edge. Inside is a hollow, sometimes descending right down through the centre of the funnel to the level of the sandy floor surrounding the boiler. The sides of the latter are often perforated by holes or clefts, so that water can enter the funnel from below and rise up inside it. While in the simplest cases the shape is that of a neat funnel or mushroom, in many others it becomes complicated and irregular, so that it may present a cluster of irregular funnels, a long narrow ribbon-like form (figure 2), and other

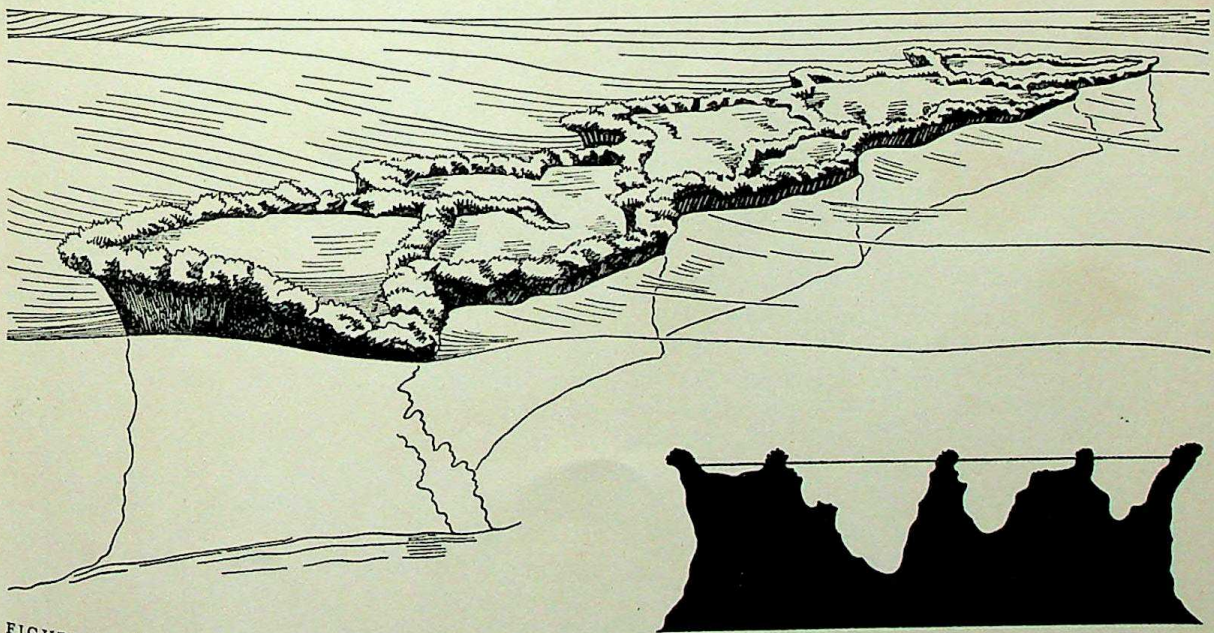


FIGURE 2 - Diagram showing the general appearance of an elongated 'boiler,' with an indication of the shape of the parts lying below the surface of the sea. Inset: Section of a similar boiler.

varieties. The raised ridges round the edges of these boilers (figures 2-4) are very characteristic of them and are formed neither of rock nor of coral, but primarily of masses of narrow worm-like calcareous tubes belonging chiefly to a gastropod mollusc known as *Spiroglyphus irregularis*. Over these tubes grows a profusion of short seaweeds—especially brown ones, among which *Sargassum* and *Dilophus* are particularly common—and it is these which give the ridges their very distinctive superficial appearance. The boilers often enclose deep and shallow pools; these pools and submerged surfaces frequently support corals and gorgonians, as well as many and varied seaweeds and invertebrates.

The rock of which the Bermuda Islands consist is a material known as aeolian limestone, which weathers along the shores into all manner of fantastic shapes and is much pitted and honeycombed by rain, sea, and wind. It was formed originally from dunes built up by wind-blown calcareous sand. The interesting feature is that the boilers just described appear to have their foundations made of this aeolian limestone, carved into peculiar shapes by the sea, but built up and veneered (and so protected from further attack by the sea) by *Spiroglyphus* and its associates near the surface and by other organisms lower down. They are not coral-reefs, but rather rocky reefs changed by wave-action and supplemented by organisms. There seems, further, to be little doubt that even the submerged reefs first described are not coral-reefs either, despite their growth of coral and gorgonians, but are bastard structures of aeolian limestone built up to a limited extent by corals and other organisms. The water in which they live is not warm enough in winter to support anything approaching a full growth of reef-building corals. Those found at Bermuda belong to a small selection of species as compared with the tropical Pacific; they are not comparable in size or profusion with those found on Pacific reefs; and they do not show a comparable range of colour and form. They are primarily brown to yellow in colour and massive in form, and the staghorn shapes so plentiful in warmer waters are represented in Bermuda only by *Millepora*. The leading reef-building staghorn genus *Acropora* is apparently absent altogether. One of the most spectacular and beautiful features of the Bermudian reefs—the lilac, purple, fawn, and brown sea-fans and other gorgonians—is a feature not of Bermuda in particular, but of Atlantic warm-water reefs as distinct from Pacific ones.

In describing the boilers, mention has been made of the calcareous tubes of *Spiroglyphus*. This animal

belongs to the gastropod family Vermetidae, whose members are not like snails or slugs but worm-like; they secrete calcareous tubes which attach them permanently to the rock. In some vermetids the individual tubes are small, but occur gregariously in such millions that they build up in time substantial amounts of what has sometimes been called worm-rock. This family Vermetidae is in itself a most interesting subject for biological research, and has not hitherto received the attention it deserves. For instance, its species, whose tubes look very like those of polychaet worms and are quite irregular, are by no means easy to classify or identify; at present we do not know how many species exist or exactly what are their limits or their distributions. To make a satisfactory identification of a vermetid, one must have the animal's operculum (which closes the mouth of the tube when it contracts) and specimens of the shell of newly born young, as well as of adults, not to mention the soft parts. In the past, many collections have consisted of the tubes alone, which are of little value. Fortunately the family is at present being revised along new lines by Myra Keen of Stanford University, who notes that in all our samples *Spiroglyphus irregularis* formed the bulk of the material, that a second species (*Petalochonchus nigricans*) was present in some of them, and that there were also true worm (polychaet) tubes in small amounts. She also notes that a third vermetid (*Spiroglyphus corrodens*), which had been supposed to be distinct from *S. irregularis*, is conclusively proved by this collection to be merely the form into which *S. irregularis* grows if not crowded; and that *Petalochonchus nigricans*, a Floridian species, had not previously been recorded from Bermuda.

The position of Bermuda on the fringe of the Sargasso Sea gives it an interest in another direction. As is well known, the Sargasso Sea is an immense eddy-like area of the Atlantic in which there float larger and smaller masses of brown seaweed known as Sargasso weed, belonging mainly to two pelagic species of *Sargassum* which are usually infertile. The origin of this weed is one of the mysteries of biology. A good deal has been written about it, and the central question concerning it is: was all this floating weed originally torn up from sea-floors in the West Indian region where *Sargassum* grows, or is it a self-perpetuating growth which has not been derived from any source now existing on the Earth, having originated from attached weed-beds in the remote past? One of the puzzles connected with it is the fact that the Sargasso weed is not specifically identical with any



FIGURE 3 - Pinnacle of aeolian limestone, surrounded by fringing reefs veneered by the vermetid gastropod *Spiroglyphus irregularis*.

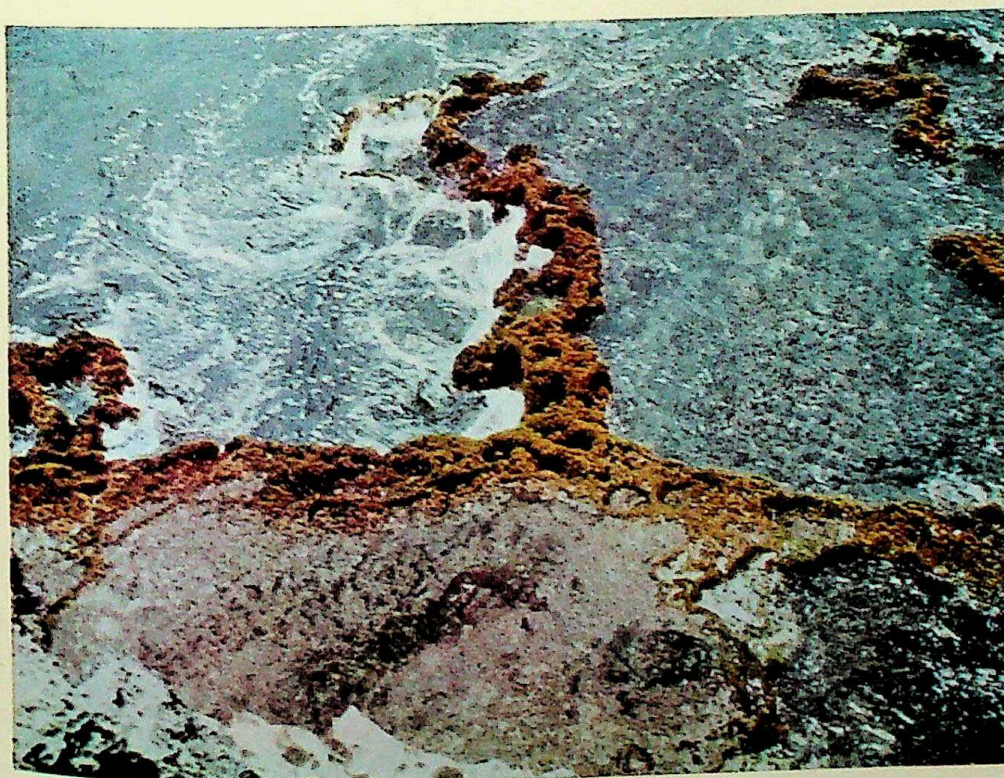


FIGURE 4 - Fringing reef seen from the top of a limestone pinnacle, showing ridges of *Spiroglyphus* overgrown by short algae.



FIGURE 5 - The coast of Gibbet Island, showing zonation between tide marks.

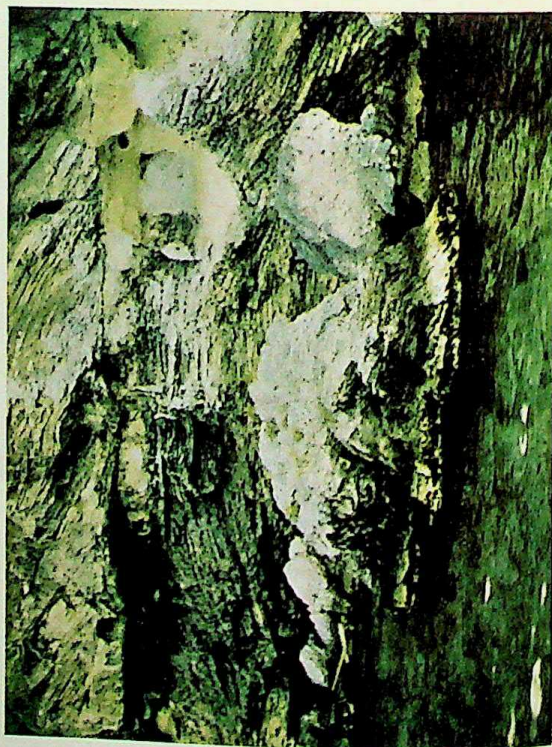


FIGURE 7 - Harrington Sound, an enclosed marine area with an unusually narrow intertidal zone.



FIGURE 6 - The outer coast of Bermuda: vegetation and acolian limestone.



FIGURE 8 - Harrington Sound: healthy submerged growth of attached Sargassum.

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FIGURE 10 - Submerged corals and gorgonians, with fish, on an offshore reef.

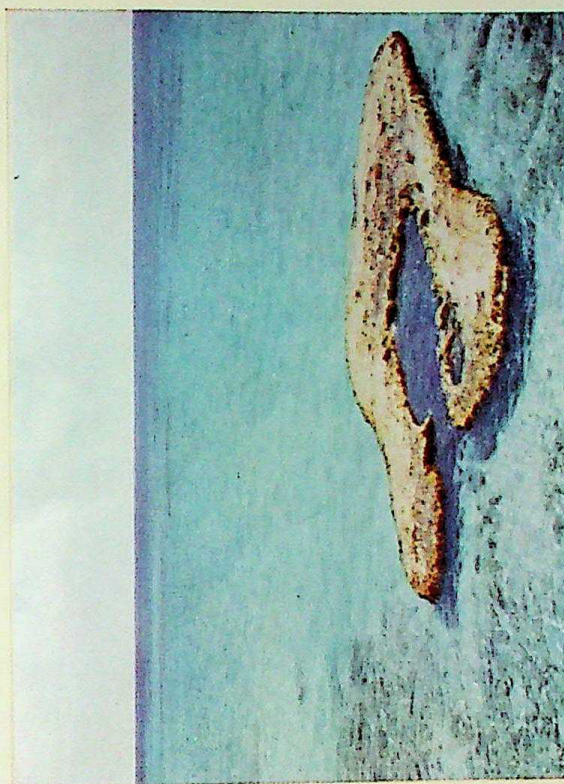


FIGURE 12 - Flat-topped boiler with central cavity.

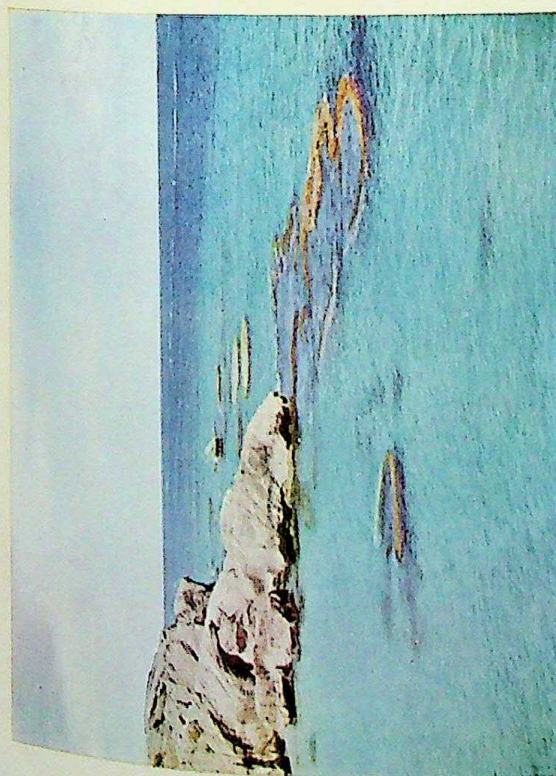


FIGURE 9 - General view of boiler reefs, forming one irregular line near the coast and another farther offshore.

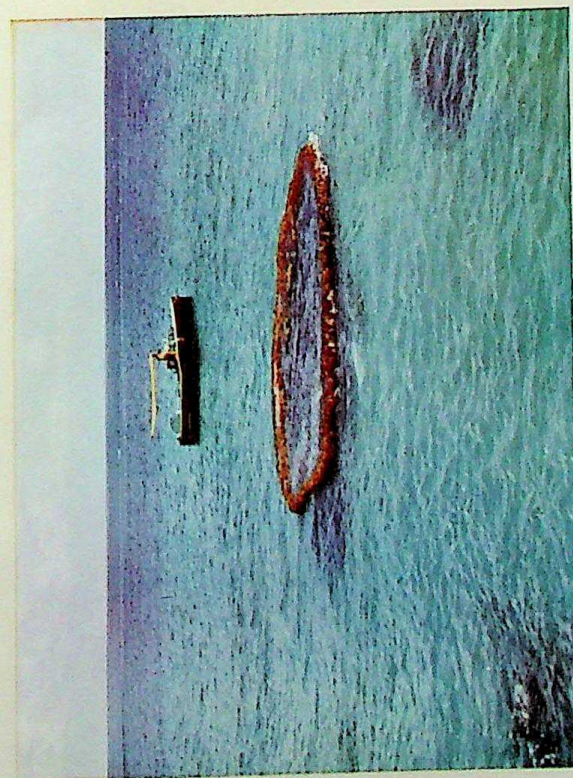


FIGURE 11 - Funnel-shaped boiler close to the coast.



FIGURE 13 - *Typical Bermuda scenery, near St George's. Oleander in right foreground; branches of native Bermuda juniper intruding at right and left.*



FIGURE 14 - *Part of a Hibiscus hedge near St George's.*

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form of *Sargassum* at present known in an attached condition. This difficulty is not insuperable, because it is known from experimental evidence that the growth-form of similar brown weeds (*Fucus*) can be changed if they are grown tangled up in wire netting instead of attached to the sea-floor, and that the *Fucales* in general tend to become modified if they grow unattached. Yet the pelagic *Sargassum* has not been produced experimentally from any attached species, so far as we know. Among the published discussions of the subject there is a particularly ingenious one by Parr [1], who surveys the known beds of *Sargassum* from which the floating weed could have been derived, and concludes that their bulk is altogether too small to have supplied the vast amount of weed in the Sargasso Sea, except on the assumption that it can be maintained by quite a small annual contribution and that it lives and grows for a very long time. In this connection we should like to draw attention to a point concerning the Bermudas. In any voyage round these islands one is likely to see floating *Sargassum*. Is there any source in Bermuda from which some of it could be derived? Here we think that, although it has long been known to botanists that species of *Sargassum* occur attached at Bermuda, it has perhaps not been realized how abundant they really are. From a little above the level of low water downwards, the growth of at least two species of this genus is extremely profuse all round Bermuda and in Harrington Sound. Many of the plants near low-water level are very short (a few inches long), but they are plentiful; and, below the water, healthy groves of plants a foot or more long are common (figure 8). It is true that these plants are quite different from the floating ones, but if the Sargasso weed is derived from any existing source, this applies wherever the source may be. It may also be true that if the total bulk of *Sargassum* round Bermuda could be weighed, it would not be great enough to count as one of the adequate sources of the floating weed. But whatever the bulk may be, it is substantial; and as the islands are subject to very powerful wave-action as well as to occasional hurricanes, much *Sargassum* must undoubtedly be torn away from the rocks, and it cannot but form a significant source of floating weed, considering how long this process has been going on—if it is capable of survival and transformation after it has become detached.

The Bermudas are no exception to the general rule that rocks between tidemarks are populated by plants and animals which are arranged in belts or zones one above another. It is now becoming

generally realized that zones of this type show some common features all over the world, as well as many local differences, but we have not as yet had a detailed description of the zonation on isolated oceanic islands in relation to these universal features. This description can now be supplied, and it is interesting to find that the Bermudas fit in very well with the general plan. On the typical open coasts the following series is to be seen (figure 5). Just above the level of low water of spring tides is the margin (infralittoral fringe) of the rich growth of seaweeds which carpets the rocks from low-water level downwards. Here there are short plants of *Sargassum* with a variety of other short algae, often ending in a strip of the brown fan-like weed *Padina*. Above this level the growth of algae is all very small (except where strong wave-action carries some of the larger species higher up), and consists rather of a short pile or moss-like growth, often intermittent, than of larger plants. The middle part of the shore (midlittoral zone) shows upper and lower subdivisions. In the lower, the rock is veneered by *Spirogyllus*, accompanied by a sparse brown pile of small algae, among which *Gelidium pusillum* v. *conchicola* seems to be important. The limpet *Fissurella barbadensis* is one of the characteristic animals. In the upper subzone are often numerous barnacles (*Chthamalus stellatus*), frequently accompanied by patches of moss-like fur consisting of short algae, among which *Polysiphonia howei* is particularly common. The proportion of barnacles to algal fur in this belt varies according to the amount of sun and wave-action experienced by any particular area of rock, and depends also on the angle of the slope. Above the midlittoral is the supralittoral fringe, near high-water level, where the rock shows one of the most typical of the universal features of the zonation, a belt in which its surface is blackened by microscopic Myxophyceae (black zone). At this level, which is often very dry, macroscopic algae are limited to specially adapted forms (particularly *Bostrychia tenella*) living in hollows, and the commonest animals are rapid isopods (*Ligia baudiniana*). The details just given apply to typical open slopes; in situations of other kinds all manner of variations may appear.

There is a very pretty problem awaiting solution in Bermuda; it is linked with the development of the zones just described, and is of geological as well as biological interest. The aeolian rock of the Bermudian shores, at the higher shore levels, has a very characteristic sculpture. It is commonly excessively pitted and honeycombed, with sharp edges, points, and angles. In the tidal belt it becomes

progressively smoothed off, until in the lower part of this belt it has quite reasonably smooth contours, covered by the *Spirogyrhus* and the pile of short algae already described. This differential smoothing is no doubt due partly, but not entirely, to incessant wave-action, and to a cementing effect of the sea-water on the rock surface. It is evidently due also, in part, to the small-scale scraping action, over the rock surface, of the thousands of animals that feed on the films and furs of small algae growing upon it. Among these animals can be included chitons, certain snails and crabs, limpets, and fishes with hard beaks, such as parrot-fish. The surface of the rock bears innumerable markings showing where these creatures have been feeding. It would be a fascinating study to determine which animals make which marks, and to discover what share each of them has in the general process of smoothing. It is certain that they can affect the zonation. We were surprised to find, for instance, that on some of the rocks the black zone mentioned above was not developed where one would expect it. Close examination showed that the Myxophyceae which blacken the rock had in fact developed at the usual levels but had been so extensively consumed by animals that the surviving residue was not enough to form the general blackening which causes a black zone, with the result that the rock was unusually pallid and barren.

One of the objects of our expedition was to compare the Bermudas with the Florida Keys. It has long been recognized that the marine population of the Bermudas is related to that of the West Indies, and it has been assumed that many Bermudian species reached the islands from the West Indies, carried by Gulf Stream water, in the form of larvae or of individuals attached to floating objects such as seaweed and logs, or by other means. We have nothing to urge against this conclusion, which is in fact strengthened by our own work, but were concerned rather to discover whether the zonation and general distribution of the species resembled that of the Keys. The islands of this 100-mile chain are subject to exceptional circumstances, including unusually shallow seas adjacent to their coasts, a peculiarly heavy fall of sediment, and reduced exposure to wave-action. Within this framework they support a tropical population, modified by the disabilities of the surroundings. In Bermuda, on the other hand, the open coast is subject to none

of these features, but there exist among the islands sheltered areas of enclosed sea which form an environment comparable to that of the Keys. In some of these we were interested to find a population and zonation very reminiscent of that characteristic of the Keys, and showing features not present on the outer, more wave-swept coasts. The zonation on the latter, while differing significantly from that of the Keys, may be understood as a rough-water modification of it. It was further interesting to find that many of the ecologically important species, that is the common ones characteristic of particular habitats, were the same in Bermuda as on the Keys. There are, of course, differences as well, and these can be used to demonstrate the contrast between the truly tropical marine climate of the Keys and the subtropical but oceanic climate of Bermuda. It appears also that the isolation of the latter has produced its own effect. The commonest shore barnacle of the Keys, for instance, is *Chthamalus stellatus*, subspecies *angustitergum*. The barnacle at present commonest in Bermuda, while again a subspecies of *Chthamalus stellatus*, differs both from the *angustitergum* form of that animal and also from *Chthamalus fragilis* (another North American barnacle), so that it is in fact a form new to science and will be described as a new subspecies by Dora Henry of Seattle, who examined our collection. This suggests that it has changed in Bermuda since it first reached the islands.

Finally it may be noted that an expedition such as this, although aiming primarily at something else, often produces incidental results which are interesting in themselves. Our boatman drew our attention one day to some very peculiar bright green barnacles growing plentifully under an overhanging cliff on an isolated offshore island. We saw at once that they were unusual, and collected some; we found them nowhere else during our three months' work. It became clear on returning to the laboratory that they belonged to a most peculiar species in which the shell, instead of consisting of 4-8 plates as in most common shore barnacles, is made up of a large number of overlapping ones. The animal is called *Catophragmus imbricatus*, and had been known previously only from a very few immature or incomplete specimens, described by Darwin in 1854 and by Verrill in 1901. It will now be possible for Dora Henry to describe the species, for the first time, from a reasonable number of well grown individuals.

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The nature of the upper atmosphere

H. S. W. MASSEY

One difficulty successfully overcome by the Everest expedition of 1953 was the thinness of the atmosphere at the heights scaled, and it might be natural to assume that at much greater levels there is so little air that no effects of any importance arise from its existence. Nothing could, in fact, be further from the truth, and some of the most important effects of the atmosphere which make life possible on the Earth's surface are located at very high levels.

Three vital functions are performed by the atmosphere—thermal insulation, removal of lethal ultra-violet light from solar radiation, and the volatilization of meteors. The ultra-violet absorption takes place mainly at an altitude between 20 and 40 km, where there is a concentration of ozone. The volatilization of meteors, on the other hand, takes place at about 100 km. The thermal effects of the atmosphere depend on its properties over a wide range of altitude. This is because a number of processes are involved—absorption of the short-wave solar radiation, which takes place at great heights, its degradation to long wavelength heat radiation, and the subsequent effects of these heat waves.

There are a number of other important upper atmospheric phenomena, and it is perhaps best to start by summarizing them as they would be encountered in the course of ascent from the ground (figure 1). After one passes through the

troposphere, the stratosphere is reached at a height of about 12 km. At about the same altitude the primary cosmic rays, consisting mainly of very energetic protons as well as other nuclei, are strongly absorbed, producing the bewildering multitude of secondary particles the study of which forms one of the main branches of fundamental research in physics. The next region of importance is the ozone layer. At 70 km an unexpected constituent becomes apparent, namely sodium. Although present in only minute concentration this sodium makes an important contribution to air-glow effects. Some 10–15 km higher there are encountered for the first time regions in which there is an appreciable concentration of ions and electrons; that is to say, the concentration is large enough to influence the propagation of radio waves. This ionized region, known as the D region, can be a source of radio fade-outs at times, especially during periods of intense solar activity, when the ionization in the region is much enhanced.

At 100 km the threshold of several important regions is reached; at this height the pressure is only about 10^{-7} of that at ground level. The temperature, having passed through two peaks and a trough, ranging from 180°K at 80 km to 270°K at 50 km, is here about 240°K . The composition of the air, as far as the major constituents is concerned, is still much the same as at ground level; about four-fifths consists of molecular nitrogen and most of the rest of molecular oxygen.

At a slightly greater altitude an important change rapidly sets in—the oxygen becomes predominantly atomic. This produces considerable changes in the absorbing power of the oxygen for solar radiation, and also makes possible certain light-emission processes which

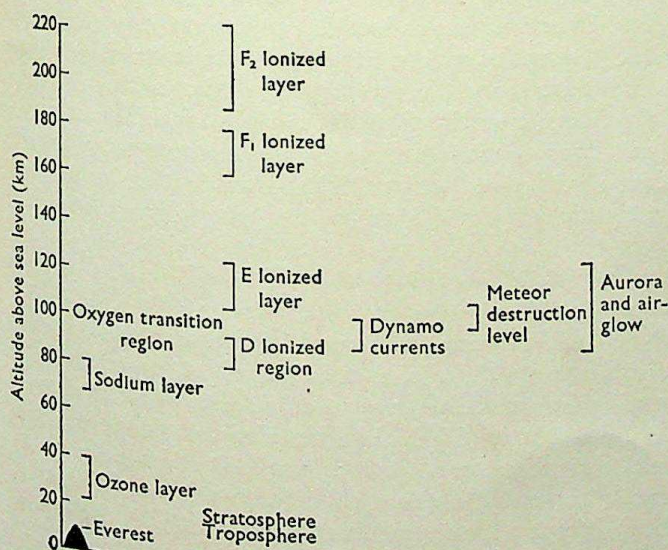


FIGURE 1—Schematic representation of the high atmosphere exhibiting the main regions of interest. (Note that the F_1 and F_2 ionized layers are shown separately. They are so only in daytime, merging at night.)

are important in determining the colour of the night air-glow.

Another technically important ionized layer is located between the 100 km and 120 km levels. It is a relatively thin (5-6 km) one, known as the E layer. Its electron concentration is considerably higher than that of the D region and the absorption very much less, so that the reflection of radio waves from the E layer plays an important part in long-distance radio propagation.

It seems probable that the main atmospheric currents which are responsible for the so-called steady lunar and solar magnetic variations flow in, or just below, the E layer. These currents result from the effect of atmospheric tidal motions on the E-region ionization, and they demonstrate the periodicity of these tides.

Many of the most interesting atmospheric light-emission phenomena arise from levels in the neighbourhood of 100 km. The night air-glow occurs throughout the year and shows little variation with latitude. It consists largely of the green and red line-emission from atomic oxygen, and band-emission from molecular nitrogen and from hydroxyl. The height of the emitting regions is probably not far from 100 km.

A more spectacular optical phenomenon is the aurora. This is much more intense than the night air-glow, and is concentrated in the so-called auroral latitudes—there is a maximum frequency of occurrence for the aurora borealis in a magnetic latitude of 67° , with a corresponding maximum in the southern hemisphere for the aurora australis. The auroral light includes strong emission at the wavelengths of the green and red oxygen lines, as in the air-glow, but the strong band-emission is from ionized, not neutral, molecular nitrogen. In the latitudes of most frequent occurrence the main light emission is from altitudes close to 100 km. At lower latitudes the much less frequent aurorae often occur at higher altitudes, some as high as 600 km. Magnetic storms are usually associated with auroral displays, and radio propagation is disturbed.

As pointed out earlier, the 100 km region is also the crematorium of most meteors. So many of them are volatilized near the same level that they produce a considerable concentration of ionization, often referred to as the sporadic, as distinct from the normal, E layer, which is at a slightly lower altitude.

There is still sufficient atmosphere well above 100 km to be of importance in many ways. Above 120 km the concentration of electrons and ions

forming the E layer falls off, quite rapidly at first, but then begins to increase again, and by day reaches a new and larger maximum at about 160-170 km. This corresponds to the F_1 layer.

After passing above this altitude, the ionization soon ceases to decrease, and then increases again to form the very broad F_2 layer in which the electron concentration is ten times as great as the maximum in the E layer. At night the F_1 layer merges with the F_2 , and there is an upward movement of the ionization to form the F layer which plays a vital part in long-distance radio propagation. At 160 km the atmospheric pressure is about 3×10^{-9} of that at ground level, while the temperature is perhaps 750°K . This upward trend in temperature almost certainly continues, so that well within the F_2 layer it probably exceeds 750°K .

Our knowledge about the upper atmosphere has been gained by a combination of direct and indirect observation. Until the last few years no direct methods were possible, but the recent remarkable developments in rocket propulsion have made it possible to carry instruments up to heights of as much as 200 km to make direct measurements of local conditions in the high atmosphere.¹ Because of the peculiar difficulties associated with use of rocket-transported instruments, the methods of observation have often to be very different from those which would be normally used in a laboratory measurement. Considerable ingenuity has been exercised in the design of rocket experiments and very important new results are now emerging. It is interesting and encouraging to note that, at least below 100 km, direct observations made by the use of rockets has largely confirmed the deductions from the indirect methods. The technique developed by Paneth and his co-workers for the micro-analysis of gases (ENDEAVOUR, 12, 5, 1953) has proved very useful in investigating samples of air recovered from rockets sent to great heights.

PRESSURE, TEMPERATURE, AND COMPOSITION

If the composition of the atmosphere is known at any altitude, measurements of any two of the three quantities pressure (p), density (ρ), and temperature (T) enable the third to be deduced. Up to about 100 km it is probable that there is no appreciable change of composition from that at ground level, and this is consistent with the observations of p , ρ , and T by various methods.

¹ A detailed account of investigations of this kind will be found in the Proceedings of the Oxford Conference on Rocket Exploration of the Upper Air, to be published shortly.

The pressure and density have been measured directly up to altitudes as high as 200 km. The pressure is determined by suitable pressure gauges (bellows gauges for low altitudes and ionization gauges for the high ones) inserted on the sides of a rocket near the tail fins. Wind-tunnel tests have confirmed that such gauges measure the ambient pressures. The density is determined from the stagnation pressure, measured by a suitable pressure gauge at the nose of the rocket. The mean values of results obtained to date are given in figure 2.

The temperature variation has been determined by several methods. If the velocity, v , of sound can be obtained the temperature can be calculated from the relation

$$v^2 = \gamma RT/M$$

where R is the universal gas constant, M the average molecular weight of the air, and γ the ratio of the specific heats of the gas. The first way in which this possibility was utilized concerned the so-called anomalous propagation of sound. Intense sounds, such as those of gunfire, are often

heard at great distances from the source, beyond an intervening zone of silence. This is because sound waves travelling at large inclinations to the horizontal are reflected by a high-temperature region, in which their velocity is increased, and thus return to earth at a distant point. The phenomenon is essentially similar to long-range radio propagation (see figure 3). The distance from the source to the point where the reflected rays, returning from different directions, are received gives the height of the reflecting high-temperature layer. Recently a more precise sound-ranging method has been introduced for use with rockets. At suitable heights grenades were ejected from a rocket in flight and exploded. The explosions were photographed and the arrival of the sound-pulses at each of five ground stations was accurately timed. From these observations the location of the explosion, the velocity of sound at different levels, and the distribution of atmospheric winds could be determined. An alternative method for measuring the speed of sound by rocket is from determination of the ratio of the pressures measured by two gauges located on the side of the rocket at different distances from the nose. This gives the Mach number of the flow past the rocket, and hence the speed of sound.

Indirect evidence about the temperature distribution has been obtained from a study of atmospheric tides. It has been found from radio observations (see below) that the amplitude of the lunar tidal oscillations is greatly enhanced at the level of the E layer. The amplitude and phase of these oscillations at high levels are quite sensitive to the temperature distribution, and Weekes and Wilkes [1] were able to show theoretically that up to 100 km the general form must be that shown in figure 2.

Finally, it has been possible to obtain information about the temperature in the E and F layers by determination, by means of radio, of the variation of electron density with height. The scale height H , which is the distance above a given level at which the pressure has fallen to $1/e$ of its value at that level, is given by $H = RT/Mg$, where R , T , and M are as previously defined and g is the acceleration due to gravity. Assuming the atmospheric composition, the temperature T may be deduced if H is known. Allowance must be made for dissociation of the oxygen above 100 km, and possibly of the nitrogen also at higher levels.

Figure 2 illustrates our present knowledge about the temperature variation at different heights. Above 100 km there is considerable uncertainty

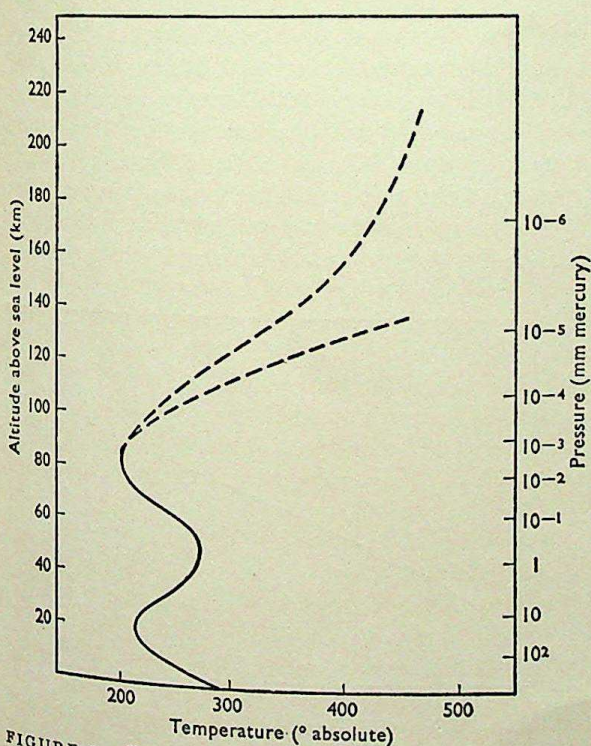


FIGURE 2 - Pressure and temperature in the atmosphere as a function of height. The full line is obtained directly from the mean of rocket observations made at White Sands, New Mexico. Above 100 km there is uncertainty in deriving the temperature from the pressure and density, owing to changes in composition. The dotted lines indicate two results obtained on two extreme assumptions.

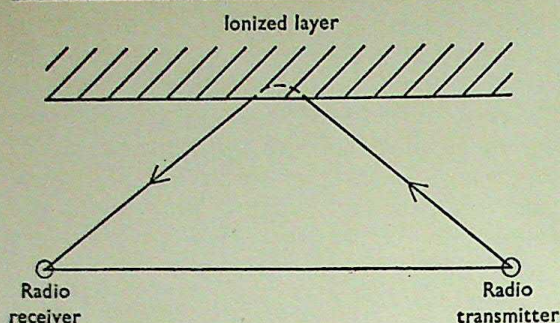


FIGURE 3 - Illustrating the long range propagation of radio waves.

due to uncertainty about the degree of dissociation of nitrogen. No direct measurements are yet available at these great heights.

THE IONIZED LAYERS

A great deal of research on the properties of the atmosphere in the E and F layers has been carried out by radio methods. The mechanism of long-distance propagation of radio waves is roughly as illustrated in figure 3, which shows a reflecting ionized layer. Furthermore, when radio waves of wavelength λ enter an ionized layer normally they are totally reflected at a level where the electron concentration n attains the value $\pi mc^2/e^2\lambda^2$, where e is the charge and m the mass of an electron and c is the velocity of light. By measuring the time-delay between vertical transmission of a ray of given wavelength and reception of the reflected wave, it is possible to determine the variation of n with height in a particular level until the observed wavelength is that for which n attains its maximum value in the layer. Further increase of wavelength then leads to complete penetration of the layer. Rocket methods now make it possible to trace the variation beyond this maximum. The method is to measure the local velocity of a radio wave by observation of the Doppler effect, due to the velocity of the rocket, on a radio signal transmitted from the rocket. The proportional Doppler shift in frequency is given by v/V , where v is the velocity component of the rocket in the direction of observation and V the phase-velocity of the radio wave transmitted from the rocket in the atmosphere round the rocket. V is given by

$$\left(1 - \frac{ne^2\lambda^2}{\pi mc^2}\right)^{-\frac{1}{2}},$$

where c is the velocity of light (total reflection occurs effectively where $V \rightarrow \infty$).¹

For a long time data of great accuracy have been obtained by radio methods using many ground stations distributed over a wide range of latitude; rocket observations, on the other hand, have hitherto been limited.

As mentioned earlier, radio-sounding methods have given information about the temperature distribution and the tidal motions at great heights. The latter observations depend on careful studies of fluctuations observed in signals from the ionized layers. These layers are far from uniform. They have a granulated structure, and the motion of the granules, which are quite large, may be deduced from analysis of signal irregularities.

The ionized layers are produced by electromagnetic radiations from the Sun. A given ionizing radiation will produce electrons at an increasing rate per unit volume as it penetrates into denser and denser atmospheric regions, until absorption begins to be large; after this point it will decrease to zero, when the absorption is complete. The particular radiations responsible for the main ionized layers are still not identified with certainty. It is of interest to note, however, that by sending up in rockets counters sensitive to X-rays, definite evidence has been obtained that, at E-region levels, there are sufficient soft X-rays in the solar radiation to produce the E-region ionization. It was suggested some time earlier by Hoyle and Bates [2] that X-rays emitted from the solar corona might be responsible for the E layer. The F ionization may be due to ionization of atomic oxygen by short ultra-violet radiation, but this is

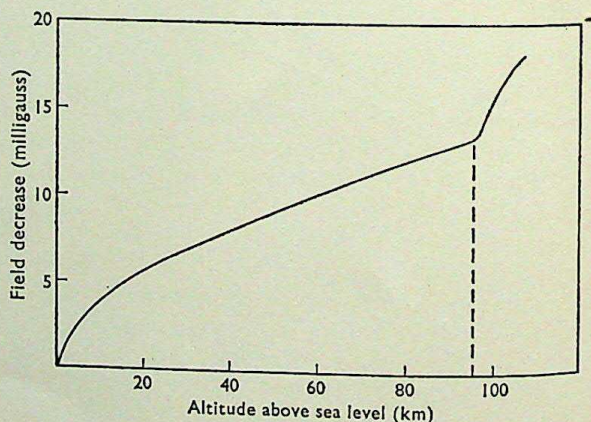


FIGURE 4 - Observed decrease of magnetic field with height off the coast of Peru, using a rocket-borne magnetometer. The sudden increase in the rate of fall of the field at 93 km indicates the presence of a current layer at that altitude.

¹ This formula neglects the effect of the Earth's magnetic field, which modifies the situation considerably.

far from certain. There is no doubt, however, from evidence obtained by observing the delay between obscuration of the solar disk and the onset of ionospheric changes during a solar eclipse, that the main layers are due to radiations travelling from the Sun with the velocity of light.

The tidal motion of the upper atmosphere exerts dynamical forces on the electrons and ions in the ionized layers, producing a current system, the nature of which is complicated by the Earth's magnetic field. According to the dynamo theory, first suggested by Balfour Stewart [3] as early as 1883, the tidal flow across the field produces a current in a direction perpendicular to each. The magnetic field at ground level includes a contribution from the field of this current system, and this will vary periodically with the tidal motion. These magnetic variations exhibit components varying with the lunar and solar tidal periods. Recent theoretical work has produced strong confirmation of the dynamo theory. Singer, Maple, and Bowen [4] performed a remarkable experiment with a rocket carrying a total-field magnetometer so that the variation of field with altitude could be measured. In passing through a current layer there should be a sudden decrease in field. Such a decrease was found to occur at an altitude of 93 km (figure 4), about the expected altitude of the base of the dynamo current layer.

THE AURORA AND AIR-GLOW

There is a clear correlation between the onset of an auroral display and the occurrence of disturbed conditions on the Sun. However, unlike the ionospheric-solar relation, there is a time-lag of one or two days between the onset of the solar disturbance and that of the aurora. This rules out solar electromagnetic radiation as the direct causative agency. The alternative is a stream of corpuscles. This cannot consist of charged particles of one sign, as their mutual repulsion would disperse the stream long before the Earth was reached. It is supposed that the stream is an ionized one containing protons and electrons in equal concentration. Strong evidence for the presence of protons in the incident stream has been afforded by the

observations of Gartlein [5] and of Meinel [6] of broad hydrogen lines in the auroral spectrum. The broadening is due to a Doppler effect which would be expected if the lines were produced by fast incoming protons capturing electrons from atmospheric atoms, and if some of these electrons were captured into excited states. Radiation due to transitions from these states would account for the observations.

There are a great number of problems still unsolved concerning auroral phenomena. In some way the protons in the corpuscular stream must be speeded up near the Earth; if they had throughout their journey the speed calculated from the time-delay of auroral onset they would not be energetic enough to penetrate to the levels at which the auroral hydrogen lines are observed. The reason for the concentration of auroral effects in a narrow belt of latitude in each hemisphere is also far from clear.

The night air-glow is a more or less steady emission of light from the sky during the night, apart, of course, from starlight and any moonlight. It is much weaker than the aurora and involves much less energy. It is almost certainly due to transfer of some of the energy stored up from sunlight during the day into radiation in the far infra-red, visible, and near ultra-violet. Thus, during the day the sunlight dissociates molecular oxygen. Partial recombination of the resulting atoms during the night will involve processes in which light may be emitted. It is of interest to note that the yellow D lines of sodium are quite prominent in the air-glow spectrum, even though the proportion of sodium at its maximum concentration is less than 10^{-8} of the main atmospheric constituents. The intensity of emission is so high that Bates has suggested that an observable enhancement might be achieved by conveying a can of sodium to the required altitude by rocket and dispersing the metal there. A day air-glow has been observed by rocket methods at altitudes above 40 km where scattered light from the lower atmosphere is sufficiently weak. Detailed spectroscopic observation of this air-glow has not yet been carried out.

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Some early goldwork

CHARLES SINGER

Gold, almost unique among metals in being found only native, has been worked for many thousands of years. Some of the earliest pieces of surviving goldwork indicate not merely a high degree of craftsmanship but wide empirical knowledge of the physical properties of the metal, as Dr Charles Singer here demonstrates in discussing some famous examples.

The working of metals, even of gold, the easiest to handle, has always been left to specialists. Such a class implies a social surplus which could not exist until men began to grow some of their food, instead of merely hunting or gathering it. This great change of habit, the Neolithic revolution, involving some sort of permanent settlement, probably began in the seventh millennium B.C. Long before that, glittering grains of alluvial gold must have drawn the attention of wandering savages, but no gold object can safely be dated earlier than the fourth millennium B.C. By then, Neolithic barbarism was itself giving way, at several points in the Near East, to the urban revolution, that is to life in walled cities, of which the earliest known was at Jericho, c 6000 B.C. From such settlements arose small city-states, true

for gold is found always in the metallic state, and there were deposits of it within trading reach of Egypt and Mesopotamia (figure 1). An ancient Egyptian map of gold-workings survives (figure 2), but few ancient mining sites yield important archaeological results, since the miner necessarily destroys his predecessors' work. Nevertheless, we know that mining techniques were well advanced by the third millennium B.C., and that the art of ventilating mines was practised in the second millennium B.C. It is possible to reconstruct, with reasonable confidence, a central European copper-mine of about 1500 B.C. (figure 3). Long before then the great empires of the ancient east had organized the import of ores and of the fuel for working them.

Much gold came to Egypt from the Nubian desert, where there are traces of ancient diggings

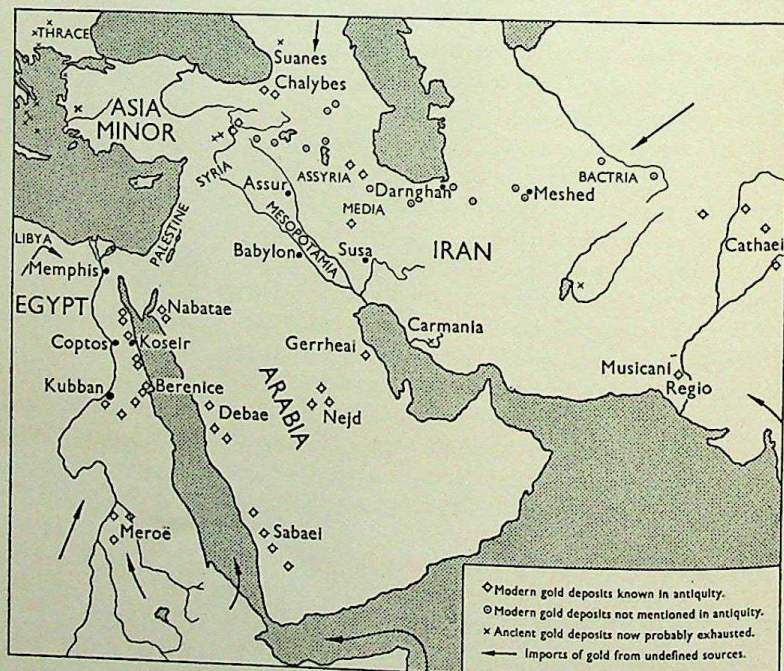


FIGURE 1—Sites of gold-workings in the Near East; only those verified by modern geology or archaeology are included. (Slightly modified from 'Metallurgy in Antiquity,' by R. J. Forbes. Leiden. 1950.)

Gold was never a utilitarian substance. It was employed only for ritual or decorative purposes. Thus while the technology of copper was of far more practical importance than that of gold, it was on gold that the finest craftsmanship was usually expended. Nor is this surprising on other grounds,

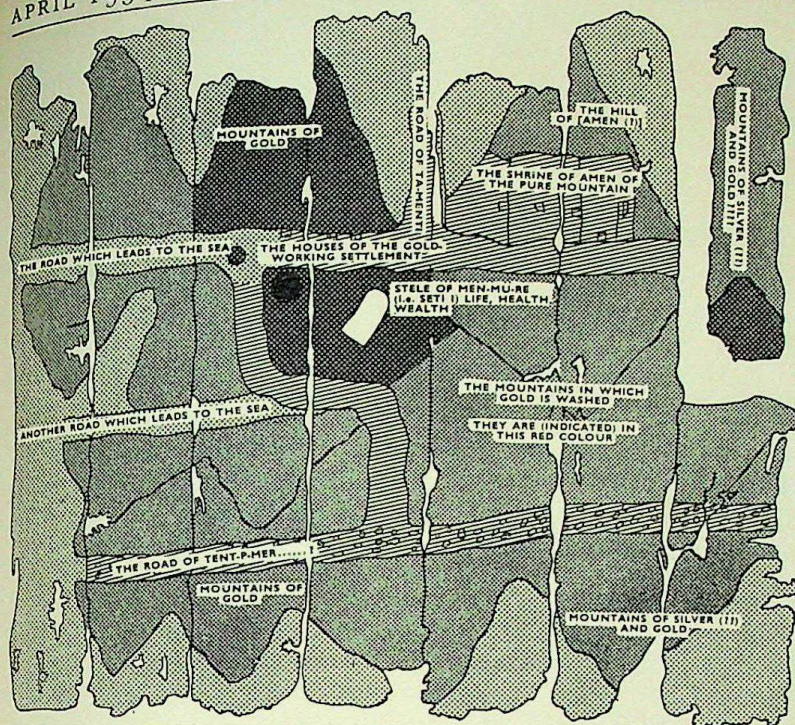


FIGURE 2 - Egyptian map on papyrus of gold mines in the Eastern Desert, with translations of the original inscriptions. c 1300 B.C. (Adapted from 'Egypt according to the Classic Geographers,' by J. Ball. Cairo. 1942.)

still containing remains of washing-tables and grinding-querns. Nubia is said to have yielded annually some 300 kg of gold, and its name in Egyptian means 'land of gold.' Gold was found there in small irregular masses in quartz veins. Fragments of the rock were hammered into pieces, pounded in mortars, and ground to powder on querns. The powder was washed on wooden tables under a gentle flow of water which left the heavy metal particles behind. This gold dust was collected on sponges and then melted into a mass. Native gold liquefies at a temperature easily attainable in a charcoal fire with even the valveless bellows or the primitive blowpipes (figures 4, 5) of the ancient Egyptians. Pure gold melts at 1063°C , but native gold always has some other metal alloyed with it. Many such alloys melt at far lower temperatures than pure gold. Thus 18 per cent of copper reduces the melting point to 878°C , and there are other gold alloys that melt at even lower temperatures.

We cannot here attempt to trace the evolution of technical skill in handling metals, but may recall that the critical stage was reached in the fourth millennium B.C., when the connection between ores and metals was first grasped. By the end of the third millennium, mastery had been attained of the elementary metallurgy of gold,

silver, copper, lead, tin, and certain other metals and their alloys, notably gold-silver (electrum) and copper-tin (bronze). An age of iron can hardly be said to have begun until the art of hardening it was mastered, about 1000 B.C., for until then iron was less useful than bronze.

Analyses of very early gold objects show that their metal always contains impurities such as silver, copper, antimony, and iron, which determine the colour. Both Egyptian and Mesopotamian technicians appreciated the variety of tints of gold, and they could even produce at will certain changes both in colour and surface texture. These skills were reached empirically and without any theory as to the nature of metals. We must content ourselves here with describing a few objects of

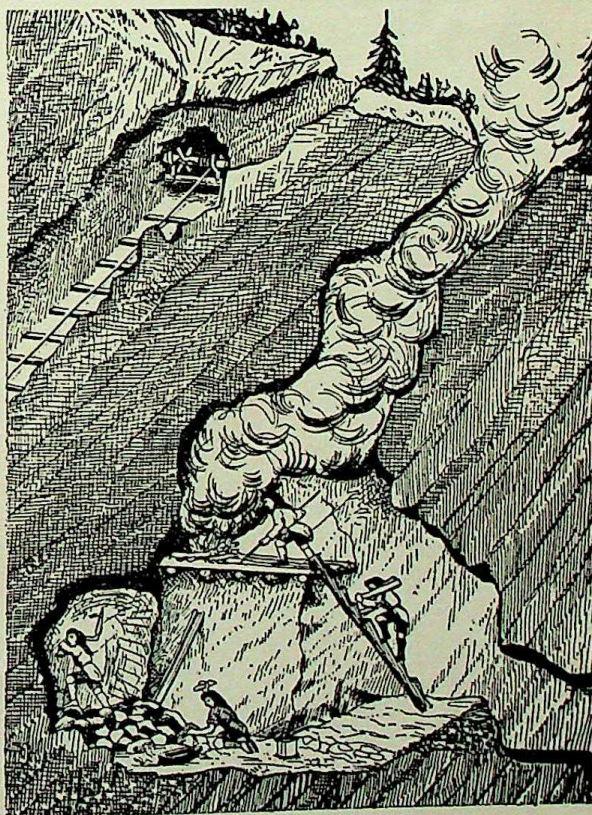


FIGURE 3 - Reconstruction of a central European copper-mine of about 1500 B.C. (From J. Andrée, 'Bergbau in der Vorzeit.' Leipzig. 1922.)

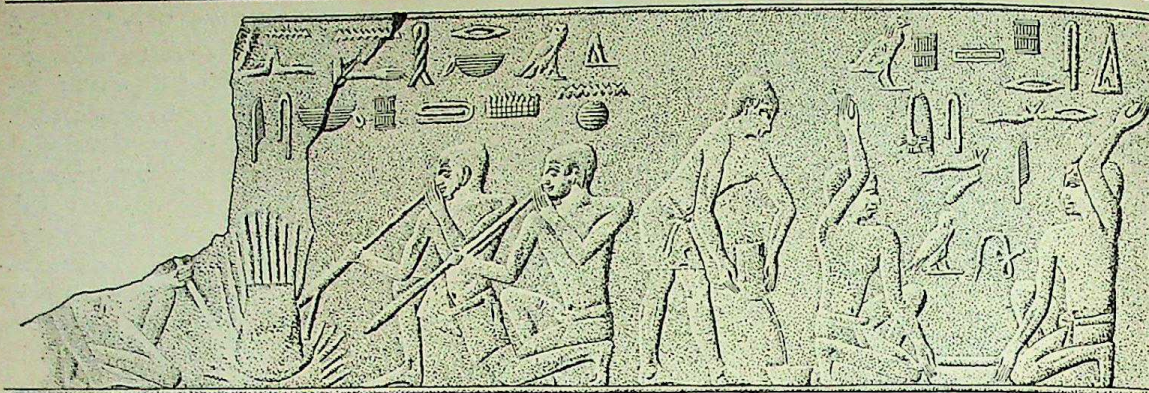


FIGURE 4 - Egyptian gold workers. Blowpipes tipped with clay are used at the fire. The man pouring from a crucible protects his hands probably with small stones; the men on the right beat out the gold with stone hammers. From a tomb at Saqqara, c 2400 B.C. (Redrawn from 'Das Grab des Ti,' by G. Steindorff. Leipzig. 1913.)

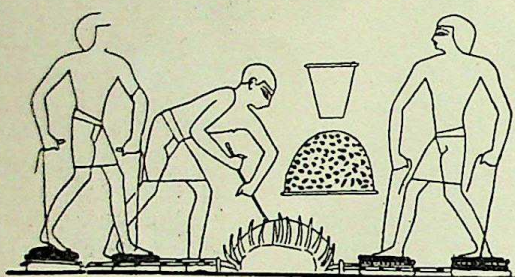


FIGURE 5 - Primitive Egyptian bellows worked by the feet, from a tomb at Thebes. c 1500 B.C. (From 'The Life of Rekhmara,' by P. E. Newberry. London. 1900.)

gold, or partly of gold, chosen as illustrating the technical expertness of these ancient craftsmen.

From Egypt of about 2400 B.C. comes a magnificent head of a hawk (figure 6). It is beaten entirely from a single sheet of gold, and finished by *repoussé* and chasing. The working was probably done largely with stone implements, but the chasing with hard copper or perhaps bronze tools. *Repoussé* is work in relief with hand-controlled punches from the back of sheet metal. To raise a pattern in low relief by blows underneath, with the decorated side resting on a yielding bed of bitumen or wood, is relatively simple, but to produce high relief or shaped figures by *repoussé* and chasing demands very great technical skill and knowledge. In this task there is a constant risk of cracking, and to avoid it there must be frequent annealing. Again, much skill and practice are needed to ensure that the thinning, consequent on hammering, is distributed evenly over the worked area. The two eyes of the hawk are formed by a single rod of obsidian, a hard, glassy substance, imported probably from Abyssinia. The rod passes right through the head and is polished in a spherical curve at each end. We know too little

of the methods then employed to grind and polish so hard a medium. Powdered quartz embedded in a 'lap' or disk of copper has been suggested as the abrasive instrument. In any event, the production of this splendid piece involved the utmost skill and resource.

An Egyptian object of a much more elaborate type is shown on the coloured plate (figure 7), which is worth consideration for its own sake. The portrayal of contoured gold presents great difficulties to the block-maker and printer. To gain an impression of their success, the plate should be

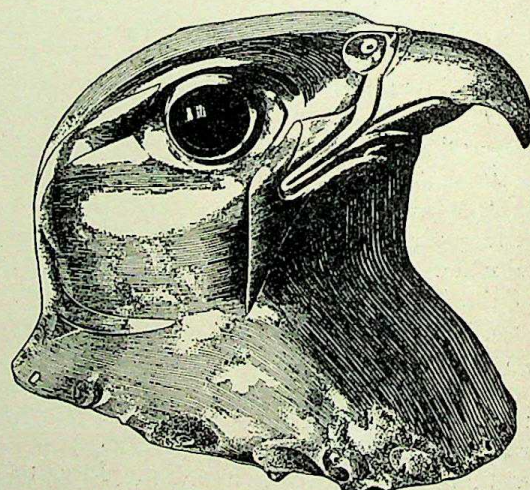


FIGURE 6 - Head of hawk, beaten from a single sheet of gold and finished by *repoussé* and chasing, from Hierakonpolis, Egypt. c 2400 B.C. (Redrawn from 'Bijoux et orfèvreries,' by E. Vernier. Cairo. 1927.) ($\times \frac{5}{8}$)

FIGURE 7 (opposite) - Part of lid of third and inmost coffin of Tutankhamun, last king of the Eighteenth Dynasty. c 1350 B.C. His tomb is the only one of a Pharaoh that has been discovered containing all its funeral furniture. (From a painting by Nina de Garis Davies.)





FIGURE 8—Full view of innermost coffin of Tutankhamun. (Photo, Griffith Institute, Ashmolean Museum, Oxford.) ($\times \frac{1}{5}$)

examined in artificial light falling obliquely.

The uniquely wealthy hoard of which this is the gem was found in the Valley of the Tombs of the Kings at Thebes in 1926. The object itself was prepared to receive the body of Tutankhamun (died 1357 B.C.), last king of the great Dynasty XVIII, who died before he was twenty. His mummy was enclosed in three concentric coffins. This, the innermost, is like the others in the form of a portrait. It is of beaten gold, varying between 2.5 and 3.0 mm thick, raised from one large sheet, and wrought into high relief by direct hammering and *repoussé*. The decoration is *cloisonné*, that is to say, to the gold background has been soldered a pattern of gold wire, the spaces enclosed by the *cloisons* or partitions being filled with coloured materials.

The figure wears on the brow the royal insignia of vulture and cobra, the former with bill of ivory and eyes of obsidian, the latter inlaid with glass, coloured to imitate turquoise, lapis lazuli, and cornelian. The hands hold the divine emblems of crook and flail, attributes of the god Osiris with whom, in death, the Pharaoh became identified. Face, neck, and hands are burnished, the feet draped (figure 8). The large collarette is adorned with bands of *cloisonné*, set with splendid coloured stones. The lower part of the body and the arms are enfolded by the protective figures of two vulture-goddesses with outstretched wings. They too are wrought in rich inlays of opaque polychrome glazes, lapis lazuli, cornelian, green felspar, and other stones. The remainder of the figure is covered with a feathered design and inscribed hieroglyphic texts.

The next object (figure 9) has not the beauty of the last two, but illustrates even better the versatility of ancient technicians in combining materials of very different kinds. It comes from a royal tomb of the first dynasty at Ur. It is of about 3000 B.C., and is one of a pair that originally supported something, perhaps the top of a small table. This representation of a goat had body, legs, and head of gold, and belly of electrum, all worked by *repoussé* and chasing, supported within by a wooden framework fastened with bitumen. The horns, the beard, and the dark locks of hair round the shoulders are blue and of lapis lazuli, the lighter locks of the lower part of the body are of shell, the eyes of lapis lazuli and shell. The tree to which the goat is attached is of gold, as is the stem that arises from the right shoulder. The rectangular base on which the creature stands is encrusted with pink and yellow sandstone and

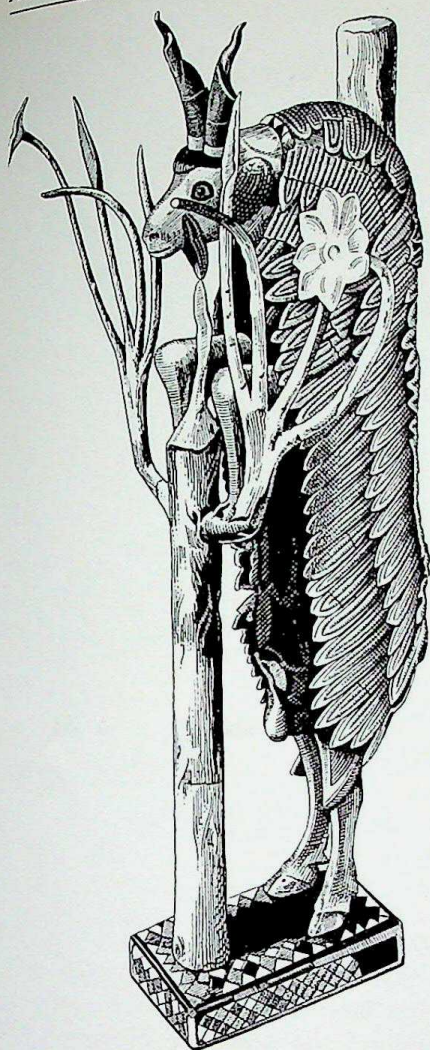


FIGURE 9—'The ram caught in a thicket.' From a royal tomb of the first dynasty at Ur, in southern Mesopotamia, of before 2500 B.C. (Redrawn from 'Ur Excavations,' Vol. II, by Sir Leonard Woolley. London. 1934.) (By courtesy of the British Museum.) ($\times \frac{1}{4}$)

white shell. The striking character of this piece has suggested the title of 'the ram caught in a thicket' (Genesis, xxii, 13 ff). However, not only is it many centuries earlier than this passage, but the 'ram' is not caught but was tethered to the tree by a silver chain, which crumbled as the object was uncovered.

The civilization that arose in the Aegean about 2500 B.C. drew something from both Egypt and Mesopotamia and was probably the main foundation of the culture of classical Greece. Its influence spread far, reaching even Britain about 1400 B.C., as was demonstrated a few months ago at Stonehenge. Its greatest centre was in Crete and its cults were specially connected with the bull and



FIGURE 10—One of the Vapheio cups (c 1600 B.C.) now in the National Museum at Athens. (Redrawn from 'The Palace of Minos,' by Sir Arthur Evans. London. 1930.) ($\times \frac{2}{3}$)

snake (figures 10 and 14), while its art is remarkable for vivid rendering of movement.

The famous pair of Vapheio cups of about 1600 B.C. (figure 10) are from a tomb near ancient Sparta. They are of beaten gold with riveted handles. The snaring and netting of wild bulls are most vividly portrayed on these cups (figure 11). One shows a drive of bulls along a wooded glen, where they are checked by a rope cradle stretched between olive-trees. From this the bull to the left has turned back and tossed one pursuer. His companion, a girl, has locked both her legs and arms around the animal's horns, making him powerless to strike. The bull to the right has avoided the barrier and galloped off. The bull in the centre is enmeshed. On the other cup a domestic cow decoys a wild bull. To the right he is nosing the cow's trail. In the centre she engages him in dalliance. To the left the herdsman, taking advantage of the situation, nooses the hind leg of the creature, who bellows impotently, 'as a dragged bull roareth when the young men haul him to the altar' (*Iliad*, XX, 404-5).

A second object from the Aegean area (figure 14) is of comparable date to the Vapheio cups and heralds a technical usage that had a very great future. This exquisite ivory statuette represents a priestess of the serpent-cult passing into a trance. She wears a tight gold belt, and her pleated skirt is decorated by a series of gold bands. She has gold armlets and in each hand holds a golden serpent, the body of which is coiled around the forearm. Locks of hair made of plaited wire once formed additional decoration round her head, and the holes of their attachment can still be seen. Such

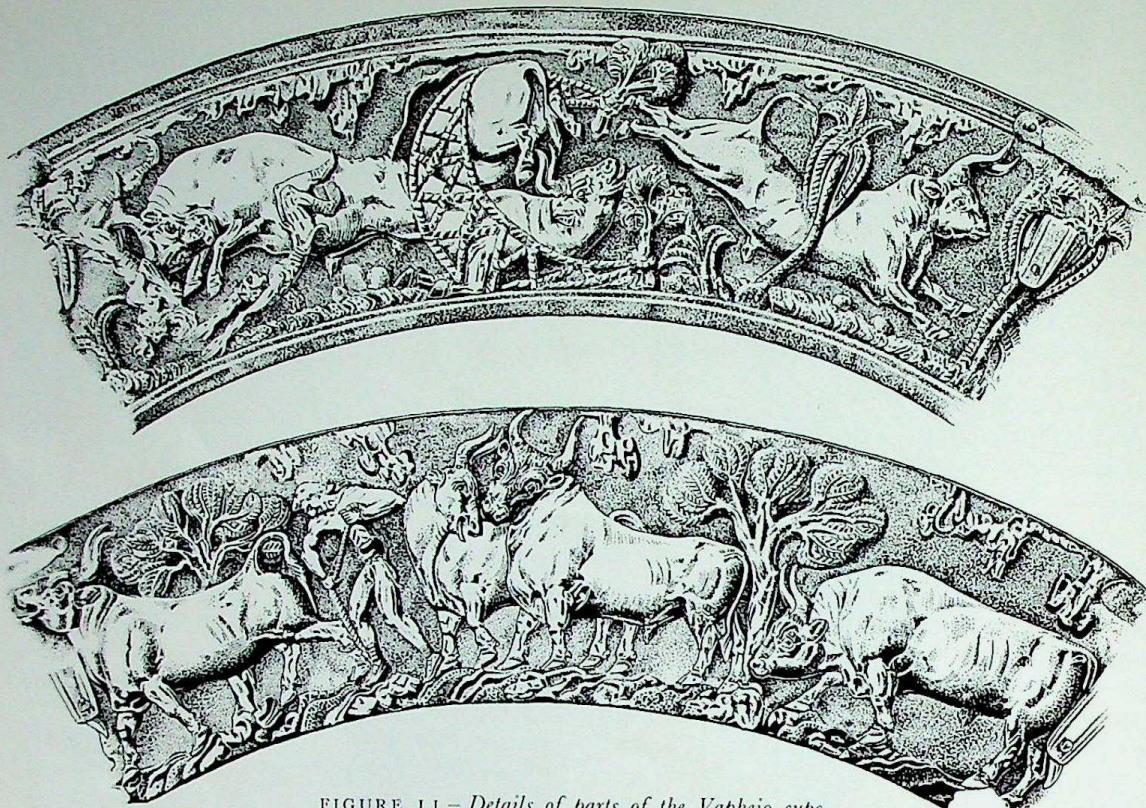


FIGURE 11—Details of parts of the Vapheio cups.

works in ivory and gold were still specially admired by the Greeks of about a thousand years later. The most famous masterpieces of their Golden Age (fifth century B.C.) were the massive statues, about 40 feet high, of the goddess Athena in the Parthenon and of the god Zeus in his great temple at Olympia, both by Pheidias, the greatest of Greek artists. They were formed of an immense number of pieces of carved ivory mounted on a great wooden frame, with draperies and ornaments of gold. Both these masterpieces, the renown of which echoed through the classical world, have now utterly disappeared. Ivory and gold (chryselephantine) Greek work of the classic period is hardly to be found, but the ecstasy of the lovely serpent-priestess may suggest some of the emotional aura with which the images of the Greek gods filled their temples.

The formation of patterns of small grains of gold soldered to a background—'fine granulation'—is not known earlier than about 2050 B.C., when it was being practised in Egypt. The art spread to the Etruscans, who colonized Italy from Asia Minor about 900 B.C. and were ultimately absorbed by the Romans. Though the art of the Etruscans is

not highly esteemed, they were extremely skilled technicians, especially with jewelry, and have never been excelled in their use of granulation. In some of the finest of this work the grains may be only $\frac{1}{180}$ th inch in diameter. Perhaps the best example is a golden bowl 4 inches in diameter (figure 12), with the pattern in double rows of grains of $\frac{1}{80}$ th inch in diameter, about 137 000 being used on this one work. The arrangement of grains and the soldering of such minute masses involve unsurpassed skill.

After Roman times the art of granulation was lost. Many efforts to recover it were made during the nineteenth century, but the modern technician could not repeat the delicacy and freedom of his ancient predecessor. The solder, however finely cut or filed, tended to flood the grains or wires, and the flux employed in the soldering was liable to boil up and displace the grains. At last the two difficulties were overcome, the first by dividing the solder into even more minute particles—chemically rather than mechanically—and the second by omitting the flux altogether. A copper compound, say the hydroxide, was used with a fish-glue to fasten the grains or wires in place.

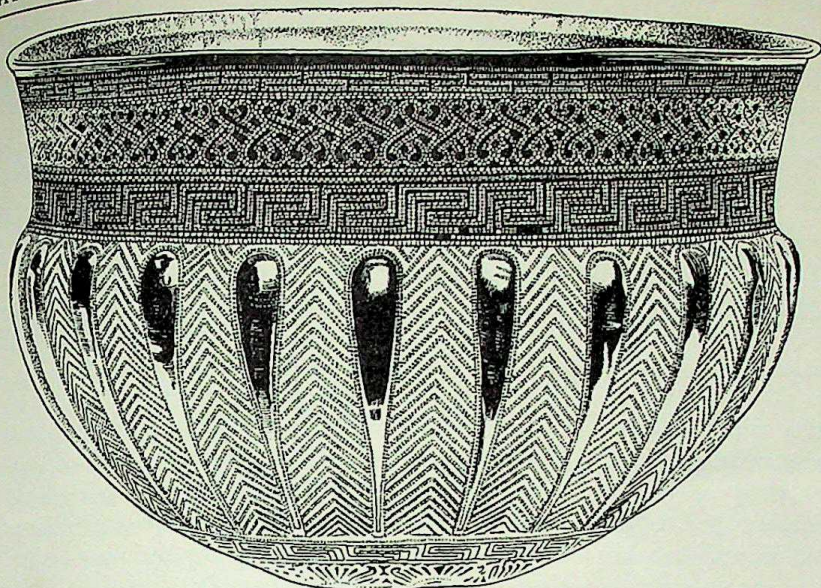


FIGURE 12 - Etruscan gold bowl with granular decoration, said to come from Palestrina. c 600 B.C. Original size. (Victoria and Albert Museum, Crown Copyright.)



FIGURE 13 - Enlarged details of the above bowl executed in modern technique.

When heated, the glue carbonized and the copper compound turned into copper oxide. The carbon then reduced the copper oxide to copper and disappeared, and a film of very finely divided copper was left in the joint. This alloyed with some of the adjacent gold, formed a solder, and joined the parts together. As a result of this discovery the modern technician can copy some of the finer Etruscan and Greek jewels and produce very beautiful original work. On the sample (figure 13) executed by this process, the largest grains measure $\frac{1}{50}$ th inch, and the smallest $\frac{1}{200}$ th inch. The work is so delicate, although strong, that daylight may be seen between the grains.

ACKNOWLEDGMENT

Much of the text of this article is based on information contained in the relevant chapters of 'A History of Technology' (The Clarendon Press, Oxford), the first volume of which is to be published shortly. All the illustrations, except figure 1, are taken from the same work, by kind permission of the Delegates of the Press.

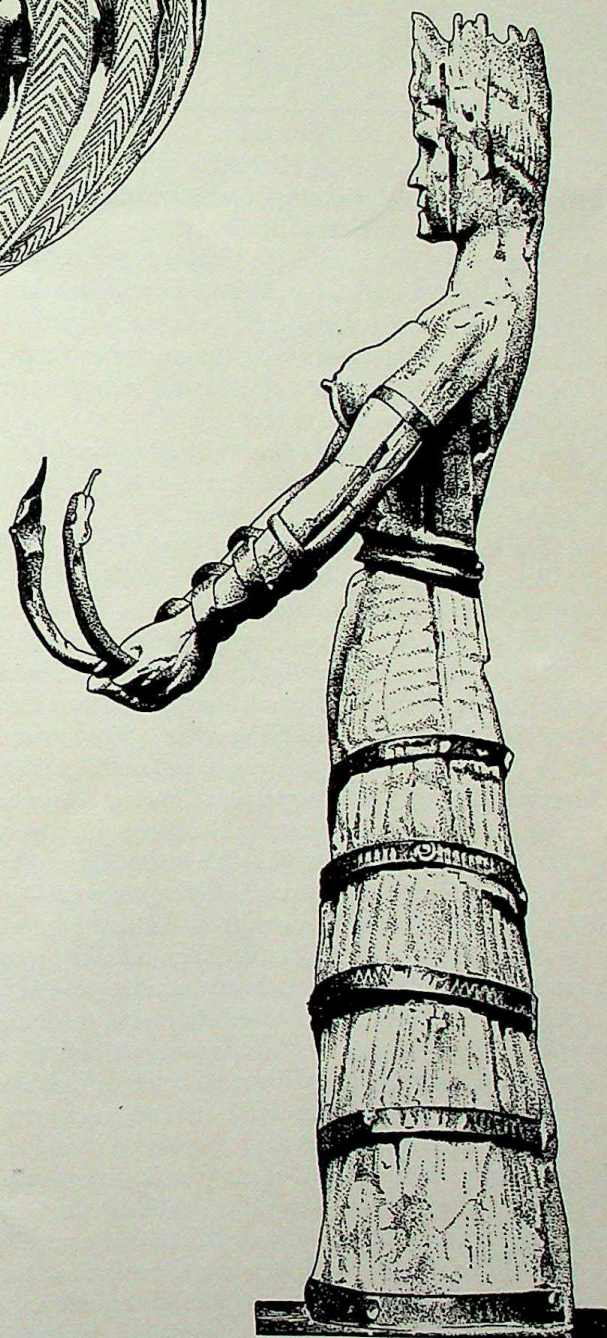


FIGURE 14 - Ivory and gold statuette from Crete. c 1500 B.C. Height $6\frac{1}{2}$ in. (Redrawn from 'The Palace of Minos,' by Sir Arthur Evans. London. 1930.)

The Alembic Club

JAMES KENDALL

The Alembic Club of Edinburgh is famous for its reprints of classical chemical investigations, including English versions of Mayow's remarkable *Tractatus Quinque Medico-physici* and of Cannizzaro's *Sunto di un corso di filosofia chimica*. Under a new arrangement the affairs of the Club are to be administered under the aegis of the Royal Society of Edinburgh, but this change will expedite, not interrupt, the publication of further reprints in this important series.

In 1889, the staff of the chemistry department of the University of Edinburgh consisted of Professor Crum Brown and five poorly paid assistants. These five assistants, on 29th October, met in the departmental library—a dark and dismal chamber of execrable proportions—and came to a memorable decision: they instituted the Alembic Club. The objects of this club, detailed on the first page of its first minute-book, were:

1. To secure the better recognition of the University of Edinburgh as a centre of chemical research.
2. To encourage the study of the history and literature of chemistry.
3. To promote by individual and collective effort the professional advancement of its members.

Many similar clubs with similar aspirations have, no doubt, been formed elsewhere at various periods, fading into oblivion after a few years. The Alembic Club, however, has flourished for more than half a century and, following a recent reorganization, will presumably flourish in perpetuity. Primary emphasis will here be laid on the accomplishment of its second object, whereby—in the words of one of its members—an unassuming body was destined to play a useful part in bringing important historical material connected with chemistry within the reach of interested readers.

The five original confederates, in order of seniority, were John Gibson, Leonard Dobbin, Hugh Marshall, James Walker, and Alexander Smith. At their first ordinary meeting, held on 19th November, 1889, Dobbin (then aged 31) was appointed secretary—an office he held for fifty-seven years. Thirteen formal rules for the regulation of the club's activities were approved; one of these fixed the maximum number of ordinary and corresponding members at thirteen. Further disregard for superstition was shown in Rule 10, appointing the fifteenth day of December as the date on which the modest annual subscription was

due. This date was carefully calculated as the thirteenth day of the thirteenth month of a year comprising thirteen months of twenty-eight days each. The Club's rule thus anticipated a reformed calendar that has come up for serious consideration recently, although 'the question of the disposal of the odd day (two in leap year), not coming within the purview of the members, was left to others for decision.'

Another rule required each member on promotion to professorial rank 'to entertain his fellows at the festive board'; this was duly observed on six auspicious occasions, as will be noted later.

The main business of early monthly meetings consisted of reports by each member on his own research and on papers of particular interest comprised in that section of current chemical journals assigned to him; in subsequent minutes discussions on a vast number of such reports are detailed. On 21st January, 1890, however, Leonard Dobbin broached a new proposal—the desirability that the club should undertake to issue a series of small books at a low price containing reprints of classical chemical investigations. 'A good deal of conversation took place as to the probable cost of such an undertaking. No definite motion was made, but the general idea was that the matter might be worth pursuing further.' With typical Scots caution, in point of fact no action was taken during the next three years.

These years witnessed a number of changes. On 28th October, 1890, it is minuted: 'That this meeting has heard with pleasure of Dr Alexander Smith's appointment as Professor of Chemistry in Wabash College, Indiana, and hereby expresses the hope that this may be but a step towards that eminent position for which his connection with this Club has so thoroughly fitted him.' Alexander Smith's career in the United States more than justified this optimism. In 1894 he became professor of chemistry in the University of Chicago,

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and in 1911 head of the department of chemistry in Columbia University, New York, and president of the American Chemical Society. He maintained an active interest in the Alembic Club until his death in 1922.

On 17th February, 1891, Ralph Stockman was admitted to ordinary membership, and monthly reports and discussions on current chemical investigations continued until 18th March, 1892, when 'none of the members having any points of interest or any business to bring forward, the Club held its first musical evening instead.' On 18th October, 1892, two resolutions were moved and adopted:

1. 'That the Club congratulates Dr John Gibson on his preferment to the chair of chemistry in the Heriot-Watt College. Item, that Dr Gibson entertain the Club to a banquet in commemoration.' Succeeding William Henry Perkin at the Heriot-Watt College, Edinburgh, Gibson occupied this chair until his death in 1914. He is still remembered in organic chemistry as participator in the Crum Brown and Gibson rule.
2. 'That the Club sympathises with itself on the transference of Dr Walker from ordinary to corresponding membership.' Walker had left for University College, London, to work under Ramsay, with whom he had made acquaintance at the British Association meeting at Leeds in 1890 during the historic debate on the revolutionary ideas of Van 't Hoff and Arrhenius. Walker and Ramsay were introduced by Ostwald, who pronounced their names in German fashion, and they continued to converse in German for a long time before discovering that they were brother Scots. The association of these two chemists considerably accelerated the acceptance of the theories of osmotic pressure and ionization in Great Britain.

To return to the Alembic Club: 1893 proved a decisive year in its development. At a meeting on 13th February, Dobbin, tired of waiting for approval of his suggestion regarding the issue of reprints, bluntly informed his fellow-members that he had arranged for Joseph Black's world-renowned dissertation of 1755, 'Experiments upon Magnesia Alba, Quicklime, and some other Alkaline Substances,' to be set up for printing entirely on his own account, and wished permission to use the name of the Club in entitling it the first of a series of Alembic Club publications, on the understanding that he should bear all financial responsibility. 'After some discussion the Club agreed to this proposal.'

There certainly does not seem to have been any initial enthusiasm on the part of his colleagues with respect to this rash experiment, but Dobbin pressed forward undaunted. On 15th July, he reported not only that Alembic Club Reprint No. 1 had already sold 'about 60 copies,' but that No. 2, 'Foundations of the Atomic Theory,' comprising papers by Dalton, Wollaston, and Thomson, for which also he made himself financially responsible—was 'newly published and selling slowly.' In 1894, three additional reprints were issued, two by Dobbin and one by Walker, whose appointment as professor of chemistry at University College, Dundee, in that year was followed by the prescriptive extraordinary meeting of the Club for 'prandial entertainment.' In 1895, no fewer than six new reprints appeared, three sponsored by Dobbin, two by Marshall, and one by Walker. Sales were still meagre, and it did not look as if income could possibly balance expenditure for many years to come. Nevertheless, the reprints were receiving very favourable notices in chemical reviews; teachers of chemistry and chemical historians both in Great Britain and in America were evincing increasing interest in them, and Crum Brown had offered to assist in financing the publication of a more ambitious project—an English version of Mayow's remarkable work *Tractatus Quinque Medico-physici*, which anticipates by a century many of the discoveries of the 'pneumatic period.' This volume, translated by Dobbin from the original Latin and thus made generally available to chemists for the first time, finally came off the press as Alembic Club Reprint No. 17 in 1907.

By that time the tide had turned, and all the early reprints had begun to make a profit. This profit was deliberately restricted to a minimum by keeping the selling price as low as possible, and sums accruing to individual sponsors were essentially devoted by them to restocking particular numbers as these neared exhaustion. Furthermore, each member at or before his decease gave all his future rights to the Alembic Club, which accordingly ultimately became the sole owner of the entire series of 21 reprints tabulated at the end of this article. By March 1953 the total sales exceeded 33 000. Leonard Dobbin's gamble had been triumphantly vindicated; a group of amateurs had succeeded in a publishing venture which seemed, at its inception, doomed to failure.

No additions to the Club's membership were made between 1891 and 1929. In 1897, Ralph

Stockman was appointed professor of materia medica in the University of Glasgow—a position he held for forty years—and another dinner celebrated the event. In 1908, a delicate situation arose; the veteran Crum Brown (who had actually attended the celebrated Karlsruhe Congress in 1860, when Cannizzaro cleared the mist from chemistry by reintroducing Avogadro's hypothesis) at last retired from the chair of chemistry at Edinburgh, and James Walker of Dundee and Alexander Smith of Chicago were placed on the short list of candidates for it. The choice between them was in the hands of seven curators of patronage—three elected by the University Court and four by the Town Council—and at that time it was customary for each candidate to pay a personal call on each curator in advance to solicit his support. This custom sometimes led to much back-stage manœuvring, but Smith and Walker, pledged by the Alembic Club 'to promote by individual and collective effort the professional advancement of its members,' astonished the curators by paying their calls arm-in-arm together, each urging the claims of the other. When the final vote went in favour of Walker by 4 to 3 Smith probably considered he had won his case.

Walker's vacant chair at Dundee immediately fell to a third club member, Hugh Marshall, whose brilliant discovery of the persulphates had gained him fellowship of the Royal Society some years previously. Unhappily, he died of typhoid fever in 1913.

On Sir James Walker's own retirement in 1928, full of honours after twenty years spent in 'securing the better recognition of the University of Edinburgh as a centre of chemical research,' he was succeeded by the author of this article, one of his own students who after graduation had migrated to Alexander Smith in America and who was privileged to become a member of the Alembic Club on his return. As recorded in the minutes, 'a further auspicious occasion terminated with the advent of closing time.' Two more of Walker's students were subsequently elected—Irvine

Masson, professor of chemistry at the University of Durham, in 1932, and Oswald James Walker, lecturer in chemistry at University College, London, in 1937.

Through all the above period, the guiding spirit of the Alembic Club was Leonard Dobbin, whose long service to the University of Edinburgh ended on his retirement with the rank of Reader in 1924. He maintained his sedulous interest in the club, however, until his death in March 1952 in his ninety-fourth year. In 1946 frailty of body—his mind remained alert and unimpaired—forced him to demit the office of secretary, but the author (who took over from him) constantly consulted him on questions of policy until the close. He became apprehensive towards the last about the future of the Alembic Club, and his successor knew that he was acting just as Dobbin himself would have wished when, with the concurrence of the other two surviving members, he asked the Council of the Royal Society of Edinburgh to accept the entire assets of the club and the responsibility for the continuance of its series of reprints.

This offer was cordially accepted, and rules for the administration of the Alembic Club Fund under the aegis of the Royal Society of Edinburgh have since been drafted and approved. The Alembic Club, fortified by the senior officers of the Society, will persist as a self-perpetuating body, and Norman Feather, professor of natural philosophy in the University of Edinburgh, and John E. Mackenzie, a former collaborator of Leonard Dobbin, who succeeded him as reader in the department of chemistry, have been added to its membership. It is planned to award quinquennially, if funds are sufficient, an Alembic Club Prize of £50 to a distinguished historian of science, and to hold Alembic Club Lectures at unspecified intervals. The first of such lectures will be formally entitled the Leonard Dobbin Memorial Lecture.

The primary aim of the club, however, will be to continue the existing Alembic Club Reprints, as listed below, and to extend the series.

ALEMBIC CLUB REPRINTS

1. *Experiments upon Magnesia Alba, Quicklime, and some other Alkaline Substances.* Black.
2. *Foundations of the Atomic Theory.* Dalton, Wollaston, and Thomson.
3. *Experiments on Air.* Cavendish.
4. *Foundations of the Molecular Theory.* Dalton, Gay-Lussac, and Avogadro.
5. *Extracts from Micrographia.* Hooke.
6. *The Decomposition of the Alkalis and Alkaline Earths.* Davy.
7. *The Discovery of Oxygen, Part I.* Priestley.
8. *The Discovery of Oxygen, Part II.* Scheele.
9. *The Elementary Nature of Chlorine.* Davy.
10. *Researches on the Arseniates, Phosphates, and Modifications of Phosphoric Acid.* Graham.
11. *Essays of Jean Rey.*
12. *The Liquefaction of Gases.* Faraday.
13. *The Early History of Chlorine.* Scheele, Berthollet, de Morveau, Gay-Lussac, and Thenard.
14. *Researches on the Molecular Asymmetry of Natural Organic Products.* Pasteur.
15. *The Electrolysis of Organic Compounds.* Kolbe.
16. *Papers on Etherification, and on the Constitution of Salts.* Williamson.
17. *Medico-physical Works.* Mayow.
18. *Sketch of a Course of Chemical Philosophy.* Cannizzaro.
19. *The Foundations of the Theory of Dilute Solutions.* Van 't Hoff and Arrhenius.
20. *Prout's Hypothesis.* Prout, Stas, and Marignac.
21. *On a New Chemical Theory, and Researches on Salicylic Acid.* Couper.

The Montpellier Botanical Garden

HERVÉ HARANT

The botanical garden of the University of Montpellier is one of the oldest in Europe, dating from the late sixteenth century, and with it are linked the names of many men eminent in botany, pharmacy, and medicine. During the last war, it suffered grievously from both direct damage and unavoidable neglect, but it is now being restored, giving promise of a future as fruitful as its illustrious past. Professor Harant describes its history and present condition.

Since the twelfth century, students from all parts of Europe have met at the famous medical school at Montpellier that grew up under the influence of the Arabs, the Jews, and the Christians of Salerno. In 1220, a bull of Cardinal Conrad, papal legate in Languedoc, consolidated the school into a university. With the spread of medical knowledge the study of natural history became an important part of the teaching at Montpellier, as is shown by documents of the time. Arnaud de Villeneuve, regent of the Faculty in his time; Michel Nostradamus, who received his doctorate in 1529; and Jean Ruel (1479-1537), all visited Montpellier to collect plant specimens even before botany had begun to be taught there. Nevertheless, from 1550 certainly, and most probably from an earlier date, regular botanical work was going on, as can be seen from article 6 of the *Arrêt des Grands-Jours* (Béziers, 1550): '*Seront tenus les dits Chanceliers, Docteurs et Conseillers, députer l'un d'entre eux Docteur des plus idoines et suffisant pour lire aux écoliers et montrer oculairement les simples; depuis la fête de Pâques jusques à la fête de la Saint-Luc, et lui constituer salaire compétant à payer par le dit Trésorier, et pour chercher les dits simples en la dite ville de Montpellier et lieux circonvoisins, seront, aux dépens de la dite bourse, députés un ou plusieurs, lesquels y vacqueront le plus diligemment que faire se pourra.*' Many well known men distinguished themselves at Montpellier: such were Rondelet, who is remembered as much for his botanical work as for his zoology, Lobel, Clusius, Bauhin, Dalechamp, and Rabelais and his co-pupil Fuchsius (after whom the fuchsia is named). It seems probable that the medical students had at that time only a small *hortulus*, of which traces have been discovered in the courtyard of the old medical school, the site now occupied by the young and flourishing faculty of pharmacy. In due course, a botanical garden became an indispensable adjunct to a medical course to which students were attracted from all

parts to Languedoc, both by the reputation of the teachers and by the richness in simples of the Mediterranean flora. The Republic of Venice had already established gardens at Padua in 1545, and Cosmo de' Medici founded those at Pisa in the following year; Bologna had its gardens in 1568, Leyden in 1577, and Leipzig two years later. In 1593 Henry IV of France commanded Pierre Richer de Belleval (1558-1623) to set up a botanical garden at Montpellier; the early appearance of these gardens has come down to us in the form of an etching attributed to Richer de Belleval himself, which is preserved in the library of the garden (figure 1). Although a part of the original garden was destroyed in 1622 during the wars of religion, there remains to this day the terraced mound dating from Richer de Belleval's time and known to all as 'The Mountain.'

For some two centuries, the garden underwent no substantial change. Some of those in charge of it during this period are now almost forgotten—Martin Richer de Belleval (1632-64), the founder's nephew, the four Chicoyneaus, Imbert (1760-85)—but many others left their mark on the history of science. During the three years in which he held the post of director, Pierre Magnol (1694-7) proposed the systematic grouping of the plants by families. He was unable to undertake the reorganization involved, but his own high reputation enhanced that of the garden. He himself must be considered an important forerunner of Linnæus in the setting up of a systematic classification, and among his pupils were Joseph Pitton de Tournefort and Antoine de Jussieu. François Boissier de Sauvages, in charge of the garden from 1740 to 1758, himself worked out a system of botanical classification based on the vegetative parts; he also ventured into the medical field in proposing a new classification of diseases. De Sauvages was followed by Antoine Gouan (1794-1803), who, however, became old and ill

before he achieved full control; he in turn gave place to Auguste Broussonet (1761-1807). Broussonet, at once botanist and zoologist, politician and traveller, introduced the ginkgo (*Ginkgo biloba*) and the mulberry (*Morus nigra*) into France; he brought new life to the garden by the erection of the great orangery and a temperate house; and by constructing in the grounds of the botany school a canal for the cultivation of aquatic plants. At his death at the early age of 46, Broussonet was succeeded by the great Pyrame de Candolle. Although de Candolle spent only nine years (1807-16) in charge of the garden, his influence was profound. Many important constructional works were undertaken during his term of office, notably the building of a hothouse and the forestry school, the digging of irrigation channels, and the setting up of the great botany school whose ground-plan remains unchanged to the present day. Dunal, de Candolle's pupil, acted as superintendent of the garden during a three-year interregnum (1816-19), but never became director, because he was not appointed to the chair of the Faculty of Medicine. He was followed by Alyre Raffeneau-Delile (1778-1850), whose work on the flora of Egypt is well known. To him we owe the beautiful *Nelumbium* in the lake in the English garden, and several interesting cycads in the glasshouses.

During the second half of the nineteenth century the post of director was held by three famous scientists. Charles Martins, director from 1851 to 1879, set up a school of medicinal plants, and constructed the English garden and the large cold-house which bears his name. He worked with equal success in the fields of meteorology, geophysics, botany, and zoology. Jules-Émile Planchon studied botany at Kiev and at Ghent before returning to direct the botanical gardens of his native town. He built a propagating house, but is chiefly remembered for his great part in the fight against the *Phylloxera* pest of the vine. Maurice Granel, during his 44 years of office (1889-1933), carried out great changes in the layout of the garden, with the help of the head gardener, Jules Daveau, a master of his craft.

During the nineteenth century, the teaching of natural history was divided between the Faculty of Medicine, the Faculty of Science, and the School (now Faculty) of Pharmacy. This explains how it came to pass that many notable botanists have worked in the garden in addition to the directors, who are traditionally professors in the Faculty of Medicine. We must not forget, for example, Charles Flahault, founder of the Insti-

tute of Botany. In our own day, my immediate predecessor, Professor Galavielle, kept the garden going during the difficult times which followed the war and the occupation.

Many changes in the layout of the garden are planned for the near future, and a great new Institute of Botany is already under construction. The present plan is shown in figure 5. With a total area of some 15 acres, the garden extends along a north-south axis and is divided into two parts by the Mountain, which runs east and west. The main avenue on the Mountain, where we find various plants dating back to the origins of the garden, runs up to the Director's Lodge, in front of which there stands a fine old Judas tree (*Cercis siliquastrum*) whose lower branches live on, though the trunk is dead and mildewed. The academic building is clothed with the beautiful green foliage of *Wistaria sinensis*. Nearby stands the recently erected statue of Pierre Richer de Belleval, the founder. Close to de Candolle's great school stand the orangery, Planchon's glasshouse, an orchid house, and a propagating house. In spite of the war we still have several fine plants here: *Dammara*, *Callistemon*, *Vanda*, *Pandanus*, *Pterospermum*, and various mesembryanthema and cycads. In the absence of many foreign plants at present lost to us and awaiting reintroduction, our borders are planted with examples of the Mediterranean flora—terebinth (*Pistacia terebinthus*) and mastic trees (*Pistacia lentiscus*), helianthema, cisti, and many others. Thyme (*Thymus*), lavender (*Lavandula*), juniper (*Juniperus*), and kermes oak (*Quercus coccifera*) are also to be seen. Elsewhere in the garden are collected plants of the coastal regions: stocks (*Matthiola*), sea-heath (*Frankenia pulverulenta*), *Coris*, *Statice*, and the various succulent *Chenopodiaceae* of the salt-laden soils known locally as *sansouire*.

Round de Candolle's garden there stand busts of many famous directors and naturalists who have worked in the garden. Near Raffeneau-Delile's ginkgo tree is the *Tombeau de Narcisse*; this is not dedicated to the beautiful youth of Greek mythology, but commemorates the stepdaughter 'Narcissa' (Mrs Temple) of the English poet Edward Young; she is said to have died at Montpellier, though she was in fact buried at Lyons. Of the *Tombeau* there remains today only a Latin inscription, but the place has been nevertheless one of pilgrimage for many, including the French writers André Gide and Paul Valéry.

Passing beyond the Mountain into the modern part of the garden, we observe a magnificent nettle-tree (*Celtis australis*), the majestic '*salabregue*'

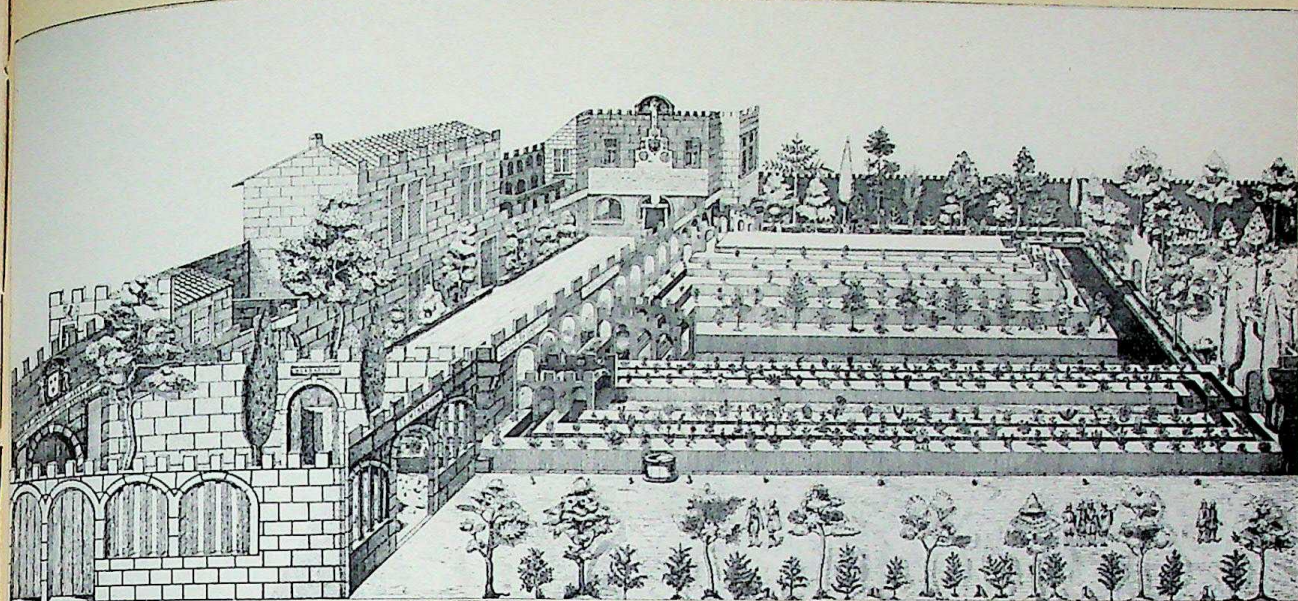


FIGURE 1 – An etching attributed to Richer de Belleval, showing the garden at the end of the sixteenth century. In the foreground, an avenue of laurels and pomegranates (Punica); among the figures is Richer de Belleval demonstrating to his pupils. On the left, the entrance to a nursery of foreign trees. In the centre, the terraces of 'The Mountain' with medicinal plants.



FIGURE 2 – Bust of J. E. Planchon, in front of the orangery.



FIGURE 3 – Bust of Charles Martins.

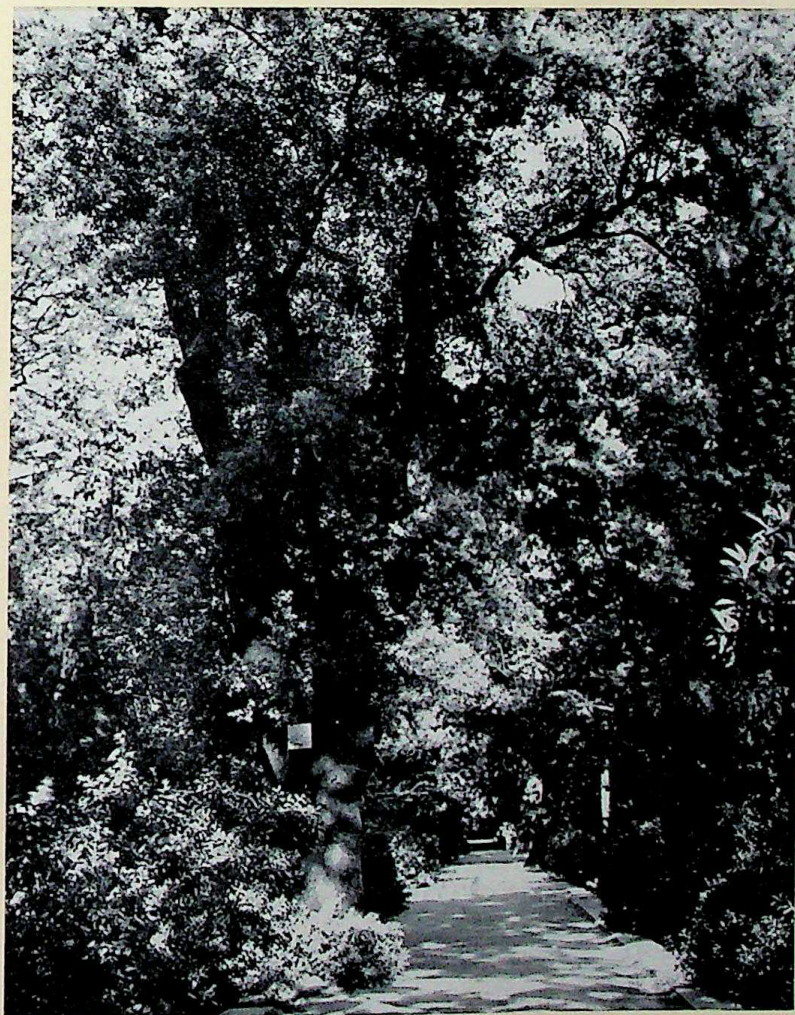


FIGURE 4 – Main avenue of 'The Mountain.'

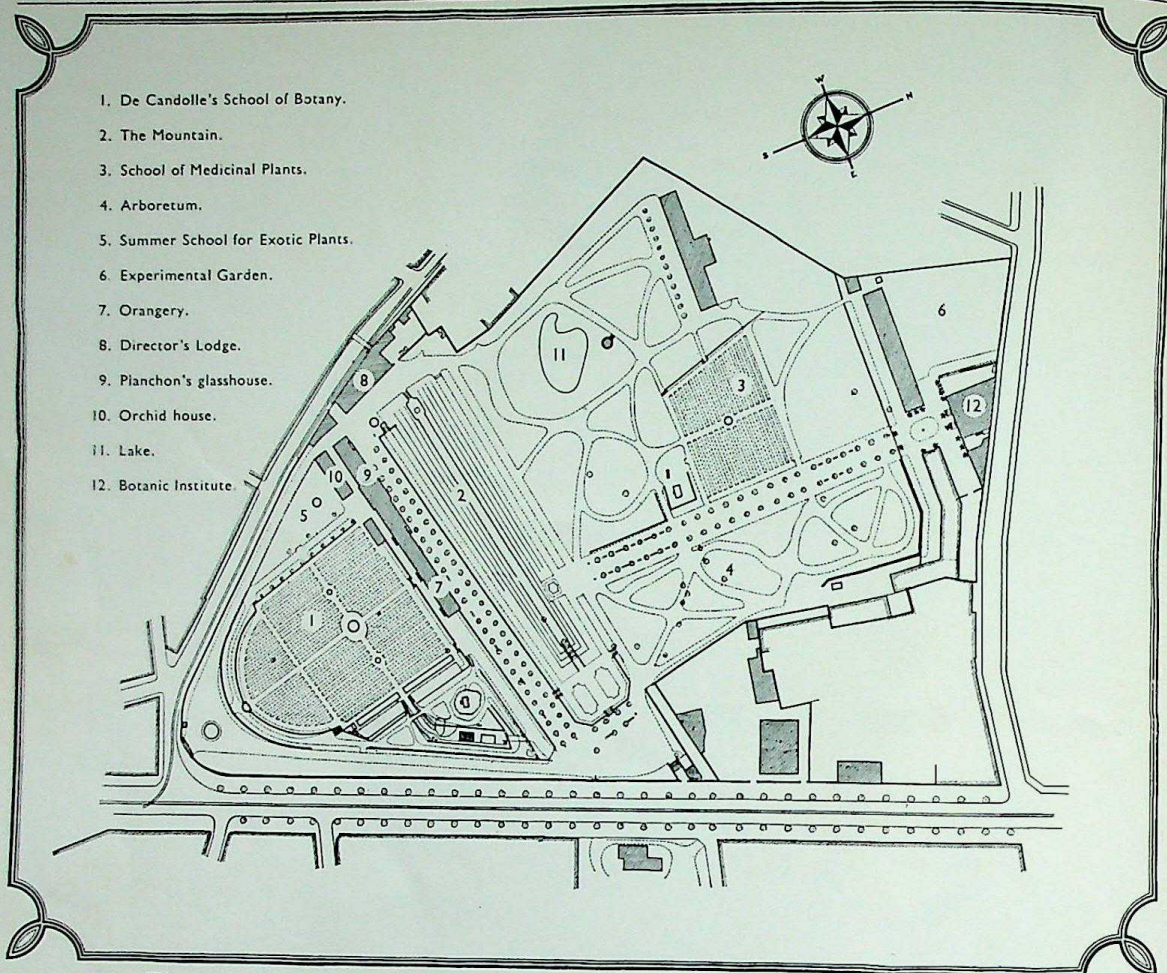


FIGURE 5 - The garden in 1942. On the left, the school of de Candolle; on the right, from east to west, the Forestry School, the School of Medicinal Plants, and the English Garden. This 1942 plan will be profoundly modified in the N.N.W. sector when the construction of the new Botanical Institute is finished. There will also be a modern glasshouse near the lake. The Botanical Institute will house the chairs of botany of the Faculties of Science and Pharmacy, as well as the chair of Natural History of the Faculty of Medicine. It will also provide accommodation for the technical and administrative services.

of Mistral. On the right stands the School of Forestry, founded by de Candolle and enlarged by Granel in 1910. Here there are many fine trees, notably an imposing elm, *Zelkova crenata*, several American locust trees, and some Osage oranges. Leaving the Forestry School, we cross the broad avenue named after de Candolle. This is bordered by horse-chestnut trees (*Aesculus*), and leads from the Institute of Botany to a statue of Rabelais set up in 1922. We next pass into the School of Medicinal Plants, with its fine collection of 800 species, then to a series of acclimatization beds surrounding an old well. Finally, we enter the English garden with its lotus lake. This lake is covered in the season with a carpet of the green leaves of these beautiful plants (*Zizyphus lotus*). Other aquatic plants surround them, less beautiful perhaps, but

no less interesting; we may mention the water-lilies, sedges, and bulrushes. Recently we have here introduced members of the flora of the Camargue, an interesting ecological association.

As we have looked back on the illustrious past history of the garden, so we must look to the future to restore its status, grievously damaged during the war. We hope to celebrate the construction of the new Institute of Botany by re-planning the garden, restoring the paths, improving the soil, and rebuilding the damaged glasshouses. We intend to set up ecological groupings, following the example of Galavielle's Mediterranean garden; to start experimental plots for studies on physiology and genetics; to introduce new specimens from the tropics; and to improve our techniques of cultivation and irrigation.

Semiconductors

KARL K. DARROW

In both practical application and theoretical study, semiconductors are of comparatively recent advent. In the last few years, however, rapid progress has been made in both directions. Semiconductors are the essential components of transistors which, being small and light and requiring comparatively little power, have already found many important uses in electronic equipment. Theoretical studies have led not only to some understanding of the nature of semiconductors but have thrown light on the structure of solids in general.

The word semiconductor ought to mean half a conductor, but, among the many definitions of it that have been made, this is one that seems never to have appeared. Originally, semiconductors were defined as substances that conduct much worse than metals but markedly better than insulators. Later, they were defined as substances which become more conductive with rising temperature. This is a definition that sets them apart from metals; it is still fairly satisfactory, but no longer applies to all. Some physicists have defined them as substances that conduct only because of the impurities they contain: this is now not broad enough. As a definition suitable for present purposes, I suggest that semiconductors should be regarded as electronic conductors in which the number of free electrons varies with the temperature. As will be seen later, this also will require modification—for instance, to take account of conduction by holes.

Semiconductors used to be regarded as oddities of nature, undoubtedly worth the attention of physicists but of little practical importance in comparison with metals. In two excellent textbooks of electricity, one published in 1912 and the other in 1916—Starling's and Pidduck's respectively—the word semiconductor is not to be found in the index. All this is now changed. The subject index of the 1952 volume of 'Physics Abstracts' shows three times as many papers listed under the heading of semiconductors as under the heading of metals. The change is partly due to two stimuli coming from applied physics: the study of rectifying junctions between semiconductors and metals, and the recent invention of the transistor. It is interesting that in some respects—though not in all—semiconductors now offer better verifications of certain fundamental theories than even the metals do.

Electronic conductors include both the metals and the semiconductors. In an electronic conductor there are innumerable bound electrons that do not concern us in the present context unless and

until they are set free; there are also free electrons. The free electrons form an electron-gas, the particles of which move hither and thither in the substance with the enormous speeds of thermal agitation. When an electric field is applied, the electron-gas starts to drift through the substance: it becomes an electron-wind. This electron-wind is the electric current. The wind-speed or drift-speed is proportional to the field-strength, except under extreme conditions to which no reference will be made in this article. The ratio of drift-speed to field-strength—in other words the drift-speed at unit field-strength—is a fundamental quality of the substance. We call it the mobility. Here must be introduced two symbols: μ for the mobility, and N for the number of free electrons per unit volume.

The values of μ and N may be found by performing a famous experiment which shows what is called the Hall effect. It was in 1879 that Hall first observed the effect: one regrets that this was twenty years before the Nobel prize was founded. Hall was also twenty years in advance of the electron theory, and therefore described his results in words other than those that will be used here.

Imagine a ribbon of an electronic conductor lying in the plane of the paper (figure 1) with a battery to drive a current along it. Let its positive end be at the right; by the old and fixed convention, the current is then from right to left, which is the opposite sense to that of the electron-wind. The equipotential lines will be at right angles to the length of the ribbon, as CD in figure 1. Let two

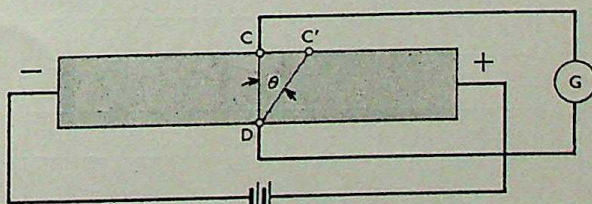


FIGURE 1—The Hall effect.

electrodes be applied to the sides of the ribbon at opposite ends C and D of such an equipotential line, and let them be connected through a galvanometer. No current flows through the galvanometer. But now let a magnetic field be applied at right angles to the plane of the ribbon, pointing (let us say for definiteness) through the plane of the paper towards the onlooker. Now a current does flow through the galvanometer. The line CD is no longer an equipotential line. The equipotential line is now tilted clockwise through an angle θ : it is C'D of the figure. One may annul the current through the galvanometer by introducing an electromotive force of appropriate size and sign into the galvanometer circuit (the conventional way), or by displacing the electrode from C to C' (the way best suited to exposition).

The electron-wind is blowing from left to right along the ribbon with a drift-speed v which is μE : here E stands for the electric field-strength. Now, an electron which is moving with speed v at right angles to a magnetic field of strength H suffers a force evH/c at right angles to both the direction of the field and the direction of motion of the electron. Here c stands for a factor which is determined by the units that are used; if classical units are used, c is equal to the speed of light in a vacuum. In this instance, the direction determined by this rule is in the plane of the paper, and the sense of the force is upward. The electrons are urged towards the top edge of the ribbon, and there they tend to pile up. As they pile up, the top edge of the ribbon becomes more negative than the bottom edge, and this goes on until the upward magnetic force on an electron is just compensated by an equal downward electric force. The horizontal electric field is exerting a rightward force eE on the electron; and taking this also into account, we see that the electrons experience a resultant electric force which is tilted at an angle θ clockwise from the horizontal. This is also the angle of tilt of the equipotential line. Its tangent is given by the equation:

$$\tan \theta = (evH/c)/eE = (e\mu EH/c)/eE = \mu H/c. \quad (1)$$

This is the fundamental formula of the Hall effect, giving the mobility of the electron-gas in terms of measurable things.

Since a semiconductor has been defined as a substance in which N , the number of electrons per unit volume, varies with the temperature, let us turn away from mobility for the moment, and see how the Hall effect determines N .

The current-density i in the wire is the product of the wind-speed, which is μE , by the number of electrons per unit volume, which is N , by the charge of the individual electron, which is e . This amounts to $Ne\mu E$, and thus for μ we have the expression i/NeE . Substituting this into (1), we find:

$$N = iH/ecE \tan \theta \dots\dots\dots (2)$$

This is another form of the basic equation of the Hall effect.

The values of N leading to the curves in figure 2 were found in this way. There is much to be learned from these curves. Before beginning to decipher them, the reader must note that the abscissa is not absolute temperature T but its reciprocal $1/T$, so that the left-hand side is the hot side. Further, the ordinate is strictly $\log N$. However, the values of N are printed along the vertical

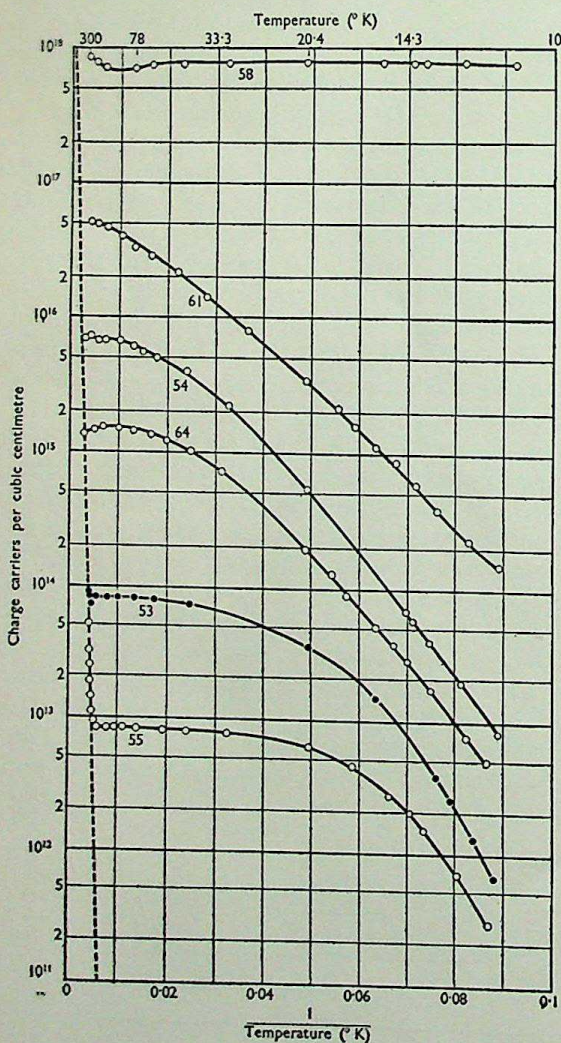


FIGURE 2 - Variation of N with $1/T$.

axis and the values of T along the top of the diagram.

These curves correspond to samples of germanium—now the most famous of semiconductors—with various admixtures of arsenic: sample No. 55 was the purest and No. 58 the most impure. Here we are able to see the origin of the long-prevailing notion that semiconductors conduct only because of the presence of impurities. On the cool side of the diagram the presence of impurities clearly has an immense effect. On the hot side, however, all the curves merge into one. It is reasonably believed that, as indicated particularly by curves 53 and 55, all the curves become part of the nearly vertical line, and that this is the curve that would be displayed by an ideally pure sample of germanium. Such a sample would be called an intrinsic semiconductor, and in general this term is applied to semiconductors in the intrinsic range of temperatures, which is that where the various curves have merged.

On the cool side, most of the curves rise with rising temperatures. This means that some of the electrons which at low temperatures are bound to atoms are set free by heat. Clearly the atoms to which these detachable electrons are bound must be atoms of impurity—arsenic atoms in this case. From these curves it is possible to estimate how much energy it takes to loosen a detachable electron from an impurity-atom; the values are generally of the order of a few hundredths of an electron-volt. Two of the curves present apparent exceptions. The curve for sample No. 58 is flat. This was the sample with the greatest concentration of impurity-atoms, and its flatness means that when the impurity-atoms are close together the work of detachment falls to so low a value that all of their detachable electrons are already freed even at

11° K. The curve for sample No. 58 slopes in the wrong sense near 300° K, which suggests that here electrons are losing their freedom as the temperature goes up. However, what this really means is that formula (2) is oversimplified and is giving incorrect values for N in this region.

From the curve in the intrinsic range it is possible to estimate how much energy it takes to loosen an electron bound into the texture of germanium, pure or impure. This is about 0.75 electron-volt. The corresponding value for silicon is about 1.10 electron-volt. These values vary with the temperature.

It has already been said that under the influence of an electric field, E , the electron-gas becomes an electron-wind. The wind-speed is μE ; the coefficient μ is by definition the mobility. Except under extreme conditions, μ is independent of E , because the free electrons are exposed to two agents that counteract each other. One of these is the field E , which accelerates the electrons up the field-direction. The term 'forward speed' may be used for the speed up the field-direction. A free electron gains forward speed from the field, and thus also gains kinetic energy. But every now and then it collides with something that takes away the forward speed and the kinetic energy that it gained since its previous collision.

These obstacles that lie in the electron's path were formerly supposed to be the atoms. This is so natural a supposition that one can scarcely imagine it to be wrong, yet it has led to conclusions that do not agree with experiment. The present hypothesis is better expressible in mathematics than in words, but may be crudely translated into words as follows: the obstacles which the electrons encounter are the elastic waves maintained by thermal agitation in the solid. This theory leads to the conclusion that the mobility should vary inversely as the $3/2$ -power of the temperature. This $T^{-3/2}$ law is exhibited by the dashed line in figure 3, where the abscissa is $\log T$ but the values marked are those of T . The curves correspond to the same samples of arsenic-containing germanium as supplied the data for figure 2. One sees that the purer the sample, the more nearly the data conform to the $T^{-3/2}$ law. It may be reasonably conjectured that in ideally pure germanium the mobility is determined by the thermal agitation of the solid—or of the lattice, as many people say. For the benefit of those who may wish to refer to the literature, it may be mentioned that this mechanism is known as lattice-scattering.

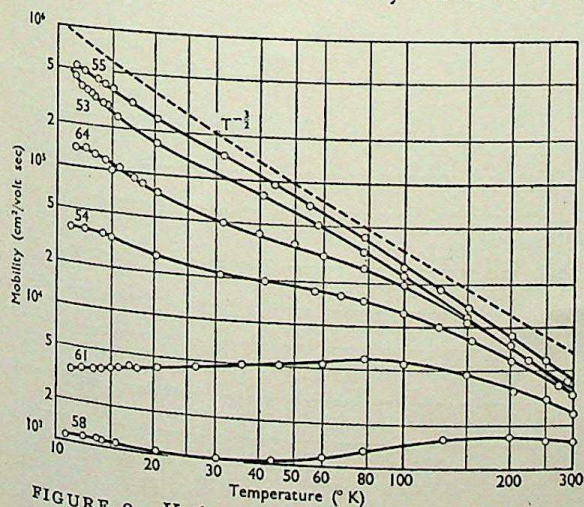


FIGURE 3 - Variation of mobility with temperature.

The curves of figure 3 also show that the presence of impurities introduces a factor that reduces the mobility, and reduces it the more effectively the greater the amount of the impurity and the lower the temperature. This further factor is the electrical charge of the impurity-atoms; such of these as have contributed to the host of free electrons are of course positively charged by reason of their loss. Such atoms deflect the electrons that approach them, and thus act as extra obstacles to the electron-wind. It is interesting to note that the mathematical theory is the same as that which Rutherford applied to the deflections of alpha-particles by atomic nuclei.

Though this article is not about metals, attention must be drawn to one of the contrasts between metals and semiconductors. In pure elementary metals, the mobility is determined by lattice-scattering; yet the mobility is usually more nearly proportional to T^{-1} than to $T^{-3/2}$. The difference arises from the fact that in metals the number of free electrons per unit volume is usually much greater than in semiconductors. Electrons so densely assembled do not conform to the familiar Maxwell-Boltzmann distribution, which is one of the stipulations required for the $T^{-3/2}$ law. In semiconductors the electron-gas is usually so rarefied that the Maxwell-Boltzmann distribution prevails, though it would be an exaggeration to say that this is always so.

Taking the expression $eN\mu E$ which was derived for the current-density i , and dividing it by E , we are left with what is by definition the conductivity of the substance, usually denoted by σ :

$$\sigma = eN\mu \dots\dots\dots (3)$$

Now we see that σ may conceivably go either up or down with rising temperature: up if the rise in N overpowers the fall in μ or if μ itself is rising, down if N is constant or if the fall in μ overpowers the rise in N . These possibilities are illustrated by the family of curves in figure 4, relating to the same set of samples of germanium contaminated with arsenic. Here $1/T$ is the abscissa, so that the cool side of the diagram is the right side; $\log \sigma$ is the ordinate.

At low temperatures, conductivity is seen to rise with temperature: this is the behaviour that used to be considered distinctive of semiconductors. At intermediate temperatures, for all but the impurest sample, σ falls with rising temperature; this is the behaviour that used to be thought distinctive of metals, but we see that semiconductors also may share it. At high temperatures the

samples are in the intrinsic range, where impurities no longer matter because the free electrons that they provide are small in number compared with those that are detached from the germanium itself.

The most sensational feature of the Hall effect has not yet been mentioned. It was said that under the circumstances depicted in figure 1—magnetic field pointing through the plane of the paper towards the onlooker—the equipotential line is tilted clockwise by the magnetic field. This is true of germanium contaminated with arsenic; it is also true of many other semiconductors and of many metals. There are, however, both semiconductors and metals for which the tilt is counter-clockwise. Sensational is the right word here, for the fact implies that in these substances there is not a drifting gas of ordinary negative electrons, but a drifting gas of positive electrons. Yet, in spite of this, physicists in general do not believe that positive electrons exist in metals or in semiconductors.

Years ago there was a German book entitled 'The Philosophy of the As If.' The Hall effect might have provided a fine example for the author,

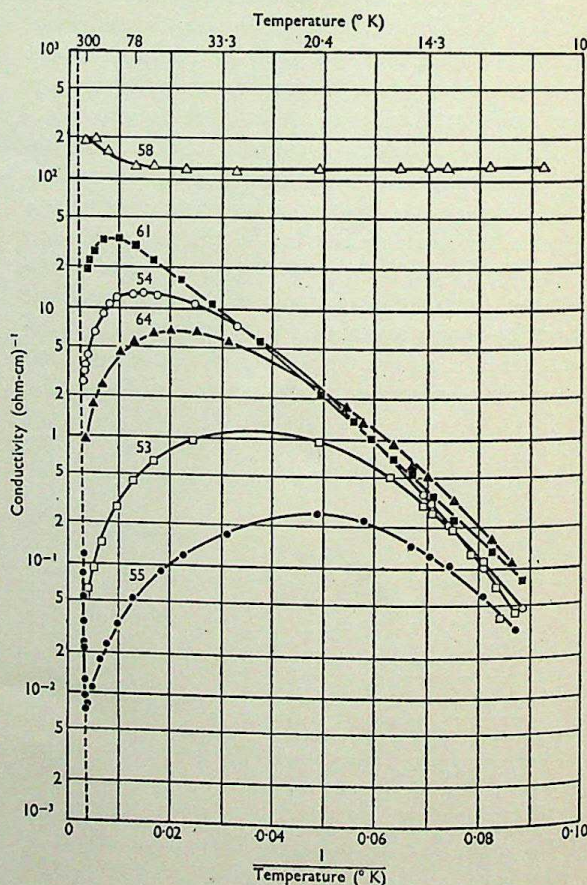


FIGURE 4—Variation of conductivity with temperature.

since physicists believe that in the substances in question negative electrons are behaving as if they were positive electrons. This statement, however, must be more carefully expressed.

What have been called the bound electrons of such a substance as pure germanium are distributed into groups, or, technically, bands. In germanium there is a group—the only one that we shall consider—which is specifically called the valence-band. At absolute zero it is presumed that the valence-band would be a filled band. What this means in theory would be hard to explain in a reasonable space; what it means in practice is that the electrons of the band do not take part in conduction. At absolute zero, could we reach it, we should presumably find that germanium is an insulator.

It is, however, possible, by heat or by any of various artifices, to prise electrons out of a filled band. Let us suppose that the valence-band is short, by say x electrons, of the number required to fill it. In this situation, quantum theory leads to a most remarkable conclusion. It is that the group or band of electrons from which x electrons are missing behaves like a gas composed of x mobile positive electrons. We describe this state of affairs by saying that the semiconductor is pervaded by a gas of 'holes.' By this usage we avoid the undesired implications of such a term as positive electrons, and we give at least a hint of the theoretical basis.

The commonest artifice for creating holes—for depopulating the valence-band, one might say—consists in mixing the germanium with an impurity of an appropriate kind. Arsenic, the impurity to which the illustrations given here have hitherto referred, is definitely not of an appropriate kind. Atoms of boron or of gallium will serve. Such atoms attract and capture electrons. They take electrons from the valence-band, and leave the holes behind. A semiconductor of such a character is called a p -type semiconductor. Germanium mixed with arsenic, or any similar substance mixed with impurity-atoms which readily give up electrons, may be called an n -type semiconductor. Impurity-atoms which readily lose electrons may be called donor atoms or simply donors, and impurity-atoms which capture electrons out of the valence-band acceptor atoms or acceptors.

The electrons captured by acceptors are immobilized. Conduction is left to the holes; the current is the hole-gas blowing like a wind through the semiconductor. The Hall experiment may be

performed; the concentration N —better now called P —of holes and the mobility μ_p of holes may be estimated by the formulae that have already been given; these, and the conductivity σ , may be plotted against the temperature, or their logarithms against $1/T$.

When plots such as these are made, they look remarkably like those of the illustrations that refer to electron-gas in germanium mingled with arsenic. The concentration P of holes rises with rising temperature, and tends to a limit. This shows that it takes work for an acceptor to prise an electron out of the valence-band. Analysis of the curves shows that the work is of the order of a few hundredths of an electron-volt, and depends on the value of P . Mobility is influenced jointly by lattice-scattering, predominant at high temperatures, and by impurity-scattering, conspicuous at low. Conductivity usually rises with rising temperatures to a maximum, then declines until the intrinsic range is reached. The analogy with electron-gas is far-reaching, and yet not perfect—another reason for avoiding such a term as positive electrons when talking about holes. The mobility of holes may be considerably less than that of electrons, say half as great. In this respect the holes behave as though they were more massive than electrons. Quantum theory indicates that, in the interior of a solid, even electrons may behave as though their mass were different from the value familiar to us in electron-beams crossing a vacuum.

Turning back to the intrinsic semiconductors, it has up to now been implied that, in the intrinsic range, electrons are loosened by heat from the texture of the germanium, and that is all. But it is not all, for the electrons in question are taken from the valence-band, and holes are left behind. In the semiconductor in the intrinsic range, there are both an electron-gas and a hole-gas. When an electric field is applied, they drift in opposite directions with unequal drift-speeds. The Hall experiment may be performed, but now the simple formulae used in this article must be replaced by others not quoted here. They involve, of course, the concentrations and the mobilities of both the electrons and the holes. In figures 2 and 4 the points which are plotted along the intrinsic part of the curves were derived from the data by the use of these formulae.

Interesting things can be observed when a limited number of holes is, so to speak, injected into an n -type semiconductor. This may be done by pressing a pointed electrode of metal against a rod of semiconductor, making it positive with respect to

the rod, and applying a voltage of appropriate sign for a limited time. Electrons are drawn out of the rod; a flock of holes is left behind; and, if there is an electric field, the flock drifts along the rod, gradually broadening and becoming vaguer in outline as it goes along, but still not losing its identity. When the flock passes another point-electrode which is negative with respect to the rod, there is an inrush of electrons through the point-electrode: by this means the advent of the flock is detected. The drift-speed of the flock may be measured by timing its departure from the first point-electrode and its arrival at the second. This drift-speed is sometimes found equal to the drift-speed computed from the Hall effect, and sometimes not. In the latter case, the discrepancy may be ascribed to oversimplification of the formulae. It should be mentioned here that a similar effect is observed when electrons are injected into a p -type semiconductor, and that the conjunction of an n -type semiconductor and a p -type semiconductor makes an excellent rectifier.

One would like to know a general rule for determining which impurities—perhaps a broader word, like anomalies, would be more fitting—produce an n -type semiconductor and which a p -type. While this is in general yet to be achieved, some progress has been made. Take, for instance, arsenic in germanium. The arsenic atom has one more elec-

tron than the germanium atom. It is very plausible to suppose that when an atom of arsenic crowds itself into a site in the lattice which would normally be occupied by a germanium atom, the extra electron becomes a sort of fifth wheel which finds no place to fit itself into, and goes rolling off through the substance as a free electron. The simile of the fifth wheel is more apt than it appears to be at first. The outermost electrons of a germanium atom number four, and in pure germanium they dispose themselves in a tetrahedral arrangement which links up with the identical arrangements of the neighbouring atoms; there is no place for a fifth electron in such a texture. Now take gallium in germanium. The gallium atom has one fewer electron than the germanium atom. Its outermost electrons number three. One may imagine that when a gallium atom has been forced into a site in the lattice which would normally be occupied by a germanium atom, there is a hole where the fourth electron ought to be, and this hole goes roaming through the substance. This is just an analogy, however, and like other analogies it may serve as an aid to memory but must not be pressed too far.

Acknowledgment. The author wishes to express his thanks to Bell Telephone Laboratories Incorporated, New York, for permission to publish this article.

Book reviews

HIGH-ENERGY PARTICLES

High-energy Particles, by Bruno Rossi. Pp. xii + 569, with half-tone and line illustrations. Constable and Company, London. 1953. 65s. net.

The appearance of a book on high-energy particles by a distinguished contributor to this branch of physics will be welcomed by the increasing number of physicists preoccupied with the subject. Until 1945, high-energy particles were the exclusive interest of the cosmic ray physicists; it is certainly time that the convergence of the interests of these investigators with those of workers using artificially accelerated particles was strengthened by the publication of a book covering both methods of studying nuclear interactions.

High-energy particles are defined as those whose energy exceeds the binding energy of nuclear particles. The book presents a comprehensive account of

our knowledge of these particles up to the end of 1951. The treatment combines an historical with a logical development of the subject. A detailed account of the theory of the electromagnetic interactions of the particles is followed by a short description of the experimental methods employed. The properties of the elementary particles are then discussed more fully, and the following chapter deals with the theory of cascade showers in considerable detail. A shorter chapter correlates the experimental with the theoretical data on electromagnetic interactions. The two remaining chapters, comprising about one-third of the book, are devoted to the data on nuclear interactions obtained from experiments with artificially accelerated particles and from cosmic ray studies. In the present state of the subject it is not surprising that the last chapter is the longest in

the book. It includes a well chosen and very beautiful collection of 16 microphotographs from photographic plate experiments, and 14 cloud-chamber pictures. There are four short mathematical appendixes, and two dealing with units and the standard atmosphere. The bibliography tabulates nearly 500 references.

The approach is predominantly experimental; meson theory is deliberately avoided. Since much of the material found in this book has not appeared outside the original literature, a handbook of this kind was urgently needed. It should help to prevent further differences arising in the nomenclature adopted by accelerator and cosmic ray physicists.

In such a rapidly developing subject one would expect that several important observations would be made even while a book upon it was passing

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through the press. This has indeed happened, especially amongst the groups using the new high-energy accelerators, but the intuitive feeling of the author for the most fruitful trends of investigation will greatly prolong the useful life of the book. The production is good, and the very many graphs, diagrams, and tables are clearly and accurately reproduced.

A. G. MADDOCK

STUDY OF TIMBER

Timber: its Structure and Properties, by H. E. Desch. Third edition, revised. Pp. xxiv + 350. Macmillan and Company Limited, London. 1933. 25s. net.

The first edition of this book was published in 1938, and quickly established itself as a clear and reliable introduction to the study of timber. For the present edition the general framework of the text has been preserved but brought up to date, and several new illustrations have been added: there are now 65 plates and 46 line drawings. The sections on the classification of trees and the nomenclature of timbers have been rewritten, as has also the chapter on defects in timber. Dr Desch feels that the seriousness of the problem of fungal and insect damage to timber has been exaggerated: he says that much of this damage could be avoided were simple basic facts more widely understood and proper maintenance observed. There are three appendixes, one of which is a useful list of the commoner hardwood tree genera, with the families to which they belong. The book also contains a selected bibliography and a subject index, which add to its usefulness. As a concise account of the structure and properties of timber it should continue to render good service to all those concerned directly or indirectly with wood technology.

EDIBLE ITALIAN SEA ANIMALS

Gli animali commestibili dei mari d'Italia, by Arturo Palombi and Mario Santarelli. Pp. viii + 349. Ulrico Hoepli, Milan. 1953. Lire 3800 net.

This is a well produced book, on art paper, with a very large number of illustrations, mostly in half-tone, and two coloured plates figuring four species of prawns. The work is a catalogue of the edible marine animals of Italian waters, including the fishes, tunicates, echinoderms, molluscs, and crustacea. The general plan is for each of the species treated to have a page to itself, with an

excellent figure which is calculated to make recognition as easy as possible, accompanied by a short description, a note on the economic value, and one on habitat and fishery. This is followed by a list of the animal's local names, including not only those which it bears in various parts of Italy but those used in a number of other countries. The description refers to its form, colour, and size. It is interesting to note that four sea urchins (*Paracentrotus lividus*, *Sphaerechinus granularis*, *Psammechinus microtuberculatus*, and *Arbacia aequituberculata*) are used as food, and that among the other invertebrates so employed are various cephalopods as well as gastropods (including limpets, *Haliotis*, and snails) and bivalves, and also crustacea (prawns, shrimps, lobsters, crabs, and *Squilla*). The authors are to be congratulated on the production of a very useful introductory handbook to this subject.

T. A. STEPHENSON

MUSHROOMS AND TOADSTOOLS

Mushrooms and Toadstools, by John Ramsbottom. Pp. 46, with 70 plates. Collins, London. 1953. 30s. net.

The ingredients for the rich and varied fare in this volume of the 'New Naturalist' series have been gathered in Dr Ramsbottom's half-century of forays in the field, the library, and the herbarium. In his treatment of the biology of the larger fungi, a discussion of their growth-requirements is used to throw light on their seasonal appearance, the section on spore characters introduces the principles of classification, and a description of sclerotial structure leads up to an account of ergot and *Cordyceps*.

In the chapters on fungus ecology, the brevity of the text severely limits the section on grasslands, marshes, and sand-dunes, but has largely spared the account of the woodland fungi. Apart from the lists provided in these sections, the book gives no systematic account of the agarics, but includes chapters dealing specifically with puff balls and earth-stars, stinkhorns and phalloids, bird's-nest fungi, and truffles.

The distinctive character of the work appears most clearly in the chapters on edible and poisonous fungi, mushroom cultivation, dry rot, truffle-hunting, fairy rings, and the history of mycology. Here the facts are interwoven with the diversity of fables brought to light by the author's inspired rummaging in the byways of literature and folklore.

A final chapter is included on the

utilization of micro-fungi in industrial fermentations and the production of penicillin.

The coloured photographs show little connection with the text, but the majority achieve verisimilitude and all are decorative.

R. W. MARSH

ESSAYS OF JEAN REY

The Essays of Jean Rey, a facsimile reprint of the original edition of 1630, with an introduction by Douglas McKie. Pp. xlv + 144 + xlv-lxxxiii. Edward Arnold and Company, London. 1951. 21s. net.

The Rey family were small landowners in the Dordogne, and Jean, author of the celebrated 'Essays,' graduated in medicine at the university of Montpellier in 1609. The exact date of his birth is unknown, but is supposed to have been about 1582 or 1583; he died about 1645. Though he acquired a considerable reputation as a physician, his claim to remembrance lies in his views on combustion expressed in the essays here reproduced in facsimile from the British Museum copy of the original edition, 1630; copies of this edition are now very rare, apparently only seven being extant. Rey believed that the source of the increase in weight which metals undergo when calcined must be sought in the air, 'which in the vessel has been rendered denser, heavier, and in some measure adhesive, by the long-continued heat of the furnace: which air mixes with the calx (frequent agitation aiding) and becomes attached to its most minute particles.' He was thus approaching the right track, though it was left to Lavoisier to set foot firmly upon it.

In an appendix to the book Dr McKie gives the text of letters passing between Mersenne and Rey, and Mersenne and Brun; these are of much interest. The publishers are to be thanked for their public spirit in making this facsimile volume available; it may be remembered that several years ago they performed a similar service in publishing a facsimile reprint of Thomas Norton's 'Ordinall of Alchimy.'

E. J. HOLMYARD

RECENT BIOLOGICAL HISTORY

A Hundred Years of Biology, by Ben Dawes. Pp. 429. Gerald Duckworth and Company Limited, London. 1952. 30s. net.

All who have written the history of a science have found their difficulties increase as they advance toward the contemporary scene, at which the method

and nomenclature of the science become familiar. The reason for this apparent contradiction is simple. Up to a point—commonly about the limit of living memory—the historian can afford to neglect all but the main line of development, but on reaching the more familiar modern period he is in the dark as to which will prove to be the main line and so has to discuss all. Thus Dr Dawes has set himself a most formidable task. He has attacked it with great courage and has produced a very useful volume. Nevertheless most of his chapters show the dichotomy suggested above—into an earlier period treated historically, and a later that is almost like a dictionary in form. This is in no way a reflection on the learning or literary skill of the author; it is inherent in the subject. He has, in fact, produced a most useful reference book which biologists of all types will find to fill a serious gap in the literature. The book is equipped with an effective bibliography and an admirable index of both subjects and names. Of the nineteen chapters the most readable are perhaps those on marine biology and on parasites, probably because these are the most susceptible of historical treatment in the proper sense. This does not imply that the less readable are less useful. Indeed, we recognize that precisely the opposite may well be the case, and that the book may develop into an increasingly valuable reference work.

CHARLES SINGER

ANIMAL LOCOMOTION

How Animals Move, by James Gray. Pp. 114. University Press, Cambridge. 1953. 16s. net.

This book is based upon the series of lectures for children and others given by Professor Gray at the Royal Institution in the winter of 1951-2. It summarizes all the work on animal locomotion that has been done during the last thirty years, mainly under the inspiration of Gray and as the outcome of his pioneer researches. The book starts with certain simple laws of mechanics, laws that apply to all movement whether living or not, and shows how evolution may account for the development of increasingly efficient organs of locomotion, fins becoming limbs and limbs becoming wings. Examples to illustrate the argument are drawn from all divisions of the animal kingdom, from the amoeba to man; the sections dealing with swimming and the creeping of serpents, subjects on which the

author has himself done so much work, are particularly interesting. Explanations are also given of some of the latest researches that have been reported, such as those on the flight of diptera, and on the electric fields that exist round the bodies of certain fish.

Professor Gray has a fascinating story to tell, and he tells it with consummate skill: his writing is simple and direct, and he clarifies complex matters so that all may understand. He unfolds his argument from point to point in a way that is delightful to follow. The drawings, though some of them are rather crude, adequately illustrate the text, and the plates present a splendid series of dramatic action-photographs.

L. HARRISON MATTHEWS

AETHER AND ELECTRICITY

History of the Theories of Aether and Electricity: The Modern Theories, 1900-1926, by Sir Edmund Whittaker. Pp. xi + 319. Thomas Nelson and Sons Limited, London. 1953. 32s. 6d. net.

The first volume of this work, which was concerned with the classical theories, was reviewed in ENDEAVOUR in January 1952. Sir Edmund Whittaker then promised a second volume dealing with the modern theories and continuing the story to the present time. The wealth of material and the many new developments in physical theories during the past fifty years have been too considerable for a single volume. The second volume continues the story to the year 1926, and a third volume, dealing with the period from 1926 to 1950, is now foreshadowed.

During, and shortly before, the first quarter of this century there was a great ferment in physical ideas. On the experimental side there were, for instance, the discovery of radioactivity, of the electron and proton, of isotopes, of the structure of the atom, of the diffraction of X-rays by crystals, of photo-electricity, of electron diffraction, and the analysis of series in spectra. On the theoretical side there were the developments of special relativity, quantum mechanics, general relativity, matrix mechanics, and wave mechanics. The aether recedes into the background.

To give an account of this revolution in physics, dealing with experiment and theory and the interaction of each on the other, has been a Herculean task. Sir Edmund Whittaker has woven these developments into a connected story with sound judgment and balanced

perspective. The principal investigations are summarized in sufficient detail for the reader to follow the train of ideas. The history is fully documented with references to the original papers. No paper of first importance appears to have escaped notice; the amount of reading entailed must have been colossal.

This great work is a mine of information and invaluable for reference. In congratulating Sir Edmund Whittaker, who is now in his 81st year, on the completion of this volume, we may express the hope that he will be able to complete his plans with the publication of a third volume bringing the story up to 1950.

H. SPENCER JONES

KOSMOS LEXIKON

Kosmos Lexikon der Naturwissenschaften, A-K. Pp. 1591. *Kosmos Gesellschaft der Naturfreunde; Franckh'sche Verlagshandlung, Stuttgart*. 1953. Halfpines, DM 29.50; half-leather, DM 36 net.

The growing extent to which science is today penetrating into everyday life has created a demand for books and dictionaries which will enable the general public interested in science to obtain information about scientific terms as mentioned in newspaper reports, radio and television talks, and general lectures. This demand seems to be most competently met by the Kosmos Society's 'Dictionary of the Sciences, with special regard to the Biological Sciences.' A list of 20 000 definitions has been compiled by a team of specialists, most of them university teachers; they are given in alphabetical order, and the present volume contains A-K.

The list consists of terms used in the various branches of science, the particular branch being represented by a symbol placed after each term, and of the names of prominent scientists, past and present, from all countries, accompanied by short biographies and an indication of their main field of work. Definitions are given in simple language which will be easily understood by a general reader, and the text is illustrated by clearly labelled diagrams and good coloured plates. So far as checked, the list is amazingly comprehensive; cross-references are added where necessary, and reference books are mentioned for those requiring more detailed information.

The dictionary will be a useful addition to reference and other libraries, and will serve as a reliable guide

through the ever-growing complexity of modern scientific terminology.

G. SCHLESINGER

HISTORY OF VERTEBRATES

Geschichte der Wirbeltiere, by Emil Kuhn-Schnyder. Pp. 156. Benno Schwabe Verlag, Basle. 1953. Swiss fr. 14 net.

This little volume, hardly more than a long pamphlet, is on the evolutionary history of the vertebrates. It is based primarily on popular lectures given in the winter of 1949-50 to the Zürich Volkshochschule, and published in its journal as a series of ten articles. These were revised and printed as a volume in 1951 and are now enlarged and again revised and provided with further notes. As it stands, the work has three excellences, all peculiarly hard to attain. First, it is clearly and simply written and beautifully illustrated—largely by J. Mayer-Gräter, who died in 1952. Secondly, it hits off happily a standard that should be intelligible to the layman and, combined with the notes, is also helpful as a palaeontological basis for the student of comparative anatomy. Thirdly, it is skilfully equipped with bio-bibliographical notes on the founders of palaeontology, from Cuvier and William Smith to Broom and Weidenreich, as their names arise in the text. This method of introducing historical material into scientific narrative is a happy idea, worth extension to other sciences. Perhaps the best, and best illustrated, section is that which deals with the difficult subject of the invasion of the land and the passage from fish to amphibian.

CHARLES SINGER

PORTRAIT OF LIEBIG

Justus von Liebig in eigenen Zeugnissen und solchen seiner Zeitgenossen, by Hertha von Dechend. Pp. 141, with three plates. Verlag Chemie, Weinheim. 1953. DM 8.40 net.

The Liebig Museum Society in Giessen has produced this attractive book; the author, and the writer of the appreciative but discriminating introduction, Professor Hartner, are members of the *Institut für Geschichte der Naturwissenschaften* at Frankfurt-am-Main. The first four pages consist of extracts from Liebig's autobiography, the last thirty-three contain a most useful list of his publications, various notes which amplify the text, brief details regarding his contemporaries, and a Liebig bibliography. The re-

mainder of the work consists of well chosen extracts from Liebig's own letters and those of his scientific colleagues, especially on the personal side, arranged chronologically on the left and right hand pages respectively. This rather condensed and disjointed presentation of the subject matter does not detract from its interest.

Liebig wrote to Wöhler 'I am attached to you with my whole soul; our friendship warms my life. I have always been sorry that you should waste your time in work which is unworthy of you'—and then the words which still ring true after more than 120 years—'throw your writing to the devil and go into the laboratory, where you belong.' Wöhler replied 'Berlin is not Giessen. What you can buy for six batzen costs a thaler here. Otherwise all lectures and all translation work could go to the devil.'

Liebig told his students: 'Don't take notes in my lectures; watch my experiments and think about them at home.' The controversy between Pasteur and Liebig is not mentioned, though criticisms by other colleagues are not excluded, and Liebig's friendship with Faraday is revealed in a pleasing manner. His incarceration in the university gaol at Erlangen for rowdy behaviour and for knocking a policeman's helmet off, and his hurried departure from Bavaria owing to political activities, throw an interesting light on his student days in 1822.

A stimulating feature of the book is the genealogical tree showing how the work and teaching of Liebig reached many of the great chemists of different countries.

F. CHALLENGER

WAVE MECHANICS

Elements of Wave Mechanics, by N. F. Mott. Pp. 156. Cambridge University Press, London. 1952. 21s. net.

In the preface, this book is described as being 'written to replace the author's "An Outline of Wave Mechanics," published by the Cambridge University Press in 1930, and now out of print. It is intended for students in the final year of an honours course of experimental physics, and also as an introduction to more advanced text books . . .' For the reviewer, the present book satisfies only the second of these intentions. It cannot be regarded as replacing the original volume of 1930, which was an outstanding work, of great value not only to students of physics but to many others who were trying to understand

the ideas of wave mechanics. It was written in such a way that most of the ideas were readily intelligible to the reader whose mathematical knowledge was slender. The present book is more concentrated and more concerned with mathematical detail, and in many places the ideas have to be extracted from the equations in a way which will make the book appeal to a much more restricted circle of readers. Many will feel that this change in the nature of the book is unfortunate, and will hope that the publishers and author will either bring the original book up to date, or will reprint the present volume with the addition of more explanatory text of the kind which the author can write so beautifully. In its present form the book should be of great value to the student of physics, and the exercises at the end of some sections will enable him to see how much he has really understood. It is perhaps unfortunate that the author should write the relation $W = h\nu$ with no mention of the mass energy, since although what is written is perfectly correct, it creates an apparent difference from other books, which may well puzzle the more elementary reader. As an introduction to more advanced text books the book needs a preliminary chapter explaining how wave mechanics came into being. Provided the reader can obtain this from lectures or some other source, the present book will be valuable as a guide to more advanced works, and many will find it useful for reference.

W. HUME-ROTHERY

ELECTROENCEPHALOGRAPHY

The Living Brain, by W. Grey Walter. Pp. x + 216. Gerald Duckworth and Company Limited, London. 1953. 15s. net.

This book is described as the first attempt to record for the general public the modern work on brain function. The actual scope is much more restricted, for it is almost entirely devoted to an attempt to correlate records of the electrical activity of the brain (the electroencephalogram) with human behaviour. The author has made notable contributions in this field, he has a sound neurophysiological background, and he is also the acknowledged leader in England in the techniques of electroencephalography. Yet one remains sceptical at the end of long chapters characterized by lively description and vivid imagery. A besetting failing of electroencephalographers is that they are so fascinated by their

tracings of electrical potentials ('brain waves') that they almost ignore the problem: how does activity in the ten thousand million individual nerve cells of the brain give rise to these potentials remotely recorded from the surface of the scalp? Electroencephalography remains thus an empirical science, and attempts are made to correlate the different kinds of brain waves with performance of the brain as a whole, or even with performance of the individual person. Such attempts would carry much more conviction if they were associated with a severely critical appraisal of the relevant data. But Dr Grey Walter is an enthusiast who is carried away by his ideas, and would have us believe that it is possible to classify human beings into distinct psychological types on the basis of a few seconds of electroencephalographic tracings. The final conclusion is that 'Enough is known today about the living brain to reduce material waste and human misery—in education, in correction, and in the development of mature personal relations.'

The best way to enjoy this book is to become infected with the zest of the author and be carried away by his enthusiasm. The ingenious models, particularly the 'tortoise,' then cease to irritate. They are obviously sources of delight and joy to their fond parents, and we can share these emotions and marvel at the conceptional ingenuity without deluding ourselves that they have scientific significance. Except for some detailed descriptive accounts of 'brain waves' the book is eminently readable. It is assured of a wide appeal, not only to philosophers and psychologists, but to those of the general public who like to read of the marvels of modern science.

J. C. ECCLES

ORIGIN OF LIFE

The Origin of Life, by A. I. Oparin, translated by Sergius Morgulis. Pp. 270, with line diagrams. Dover Publications Inc., New York. 1953. Cloth, \$3.00; paper, \$1.70 net.

The interest that has been taken in recent years in the origin of life is second only to that taken in space navigation and is related to it, both because it represents a similar adventure into the recesses of time, and because of the realization that if life on this planet is not unique and we may expect to find other forms of life in other worlds, we ought first to get some idea of how life originated on this one.

The new interest is not like the old, the establishment of the shocking idea that life might not have been created but that it just grew. Most scientists are prepared to accept that: what they and the public now want to have is a more precise idea of how it happened. For this, nothing that has yet appeared is better than Oparin's 'Origin of Life,' of which a popular edition has just been published, with a new introduction by Professor Morgulis. This is all the more welcome inasmuch as the earlier edition is almost unobtainable.

Although it has not been able to include any of Oparin's most recent contributions, which amplify and deepen his original ideas, the book has stood the test of time well, and its central thesis is unshaken. This is that life on the Earth arose out of the interaction of light with the gases methane, ammonia, and carbon dioxide, which would form the natural atmosphere of a primitive planet. Indeed, in one respect it has received a remarkable confirmation, for Urey and Miller have been able to make several amino acids, the characteristic components of the proteins, by electrical excitation of such a mixture of gases. Professor Morgulis has added other expansions and confirmations, notably on the importance of protein enzymes. In one respect I fear he would not find Oparin in agreement with him, that is when he seeks to equate the virus with the gene and to imply that life originated from chance variations operating on a concentration of complex substances. In Oparin's view the processes and substances of life form and have always formed an indissoluble whole.

Oparin's conclusions can be summed up in his own words, taken from his article in the Soviet Encyclopaedia¹: 'Life is a particular form of movement of matter which appeared at a certain stage of its historic development and is represented at the present moment on our planet by an enormous number of individual systems—the organisms.'

J. D. BERNAL

ADSORPTION

The Dynamical Character of Adsorption, by J. H. de Boer. Pp. xv + 239. Oxford University Press, London. 1953. 30s. net.

De Boer has examined the phenomenon of adsorption in terms of the dynamic character of molecules, their number, speed, direction of motion,

¹ French translation in *Questions Scientifiques*, II, Paris, 1953.

time of lingering at surfaces. For those who have difficulty with molecular magnitudes and numbers per cc, he provides a magnified picture in which the molecules are blown up to the size of bees and a square centimetre becomes a 200-mile square erected on a baseline from Hastings to Torquay. Each phenomenon is illustrated with reference to this 'gas of super bees.' The writing is fluid and dynamic but never surrenders the accuracy essential to a scientific text which is designed to provide the student with the fundamentals of the subject and the advanced worker in the field with much to meditate upon concerning unsolved problems. It deals mainly with adsorption due to physical interactions between surfaces and fluids, only slightly with chemisorption. It provided both pleasure and instruction to one who has spent many moons in study of the phenomenon.

HUGH TAYLOR

POLLEN OF MONOCOTYLEDONS

New Zealand Pollen Studies: The Monocotyledons, a Comparative Account, by Lucy M. Cranwell. *Bulletin of the Auckland Institute and Museum*, No. 3. Pp. 91. Harvard University Press, Cambridge, Mass.; Auckland Institute and Museum, Auckland, N.Z. 1953. Cloth, 30s; paper, 20s. net.

Miss Lucy Cranwell (Mrs Watson Smith) published the first of her 'New Zealand Pollen Studies' (in key form) in 1942. The present work, on a much larger scale, is a systematic account of the pollen grains of the monocotyledonous plants of New Zealand. All the 17 relevant families are treated in proportion to their palynological interest and importance, the lily, sedge, and orchid families therefore being dealt with at greater length than the remainder. The account of each family is prefaced by a *résumé* of previous work from the time of Grew and Malpighi onwards. Descriptions of the various species follow: these, read in conjunction with the many excellent photographs, should greatly facilitate the task of future pollen analysts. The work also includes a glossary (very necessary, the terminology of pollen morphology being in the fluid condition that it is), keys to pollen determination, a synoptic table of pollen characters, a bibliography of 247 items, and an index.

Mrs Watson Smith's monograph is an outstanding contribution to a growing subject.

H. A. HYDE

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Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

BIOCHEMISTRY

Antibiotics, by F. A. Robinson. Pp. 132. Sir Isaac Pitman and Sons Limited, London. 1953. 15s. net.

BIOLOGY

Biologie der Zelle, by Erich Ries, edited by Manfred Gersch. Pp. 552. B. G. Teubner Verlagsgesellschaft, Leipzig. 1953. DM 24.40 net.

Symposia of the 6th International Congress of Microbiology, in six volumes: Bacterial Cytology; Growth Inhibition and Chemotherapy; Nutrition and Growth Factors; Microbial Metabolism; Interaction of Viruses and Cells; Actinomycetales, Morphology, Biology and Systematics. Fondazione Emanuele Paterno, Rome. 1953. Lire 2000, 1000, 1400, 1000, 1300, and 1600 respectively.

Tissue Culture, by E. N. Willmer. Pp. 175. Methuen and Company Limited, London. 1953. 9s. 6d. net.

BOTANY

The Hidden Life of Flowers, with photographs by R. H. Noailles. Translated from the French text of J. M. Guilcher. Pp. 93. Andrew Melrose Limited, London. 1954. 5s. net.

Plant Respiration, by W. O. James. Pp. 281. Oxford University Press, London. 1953. 30s. net.

CHEMISTRY

Les Applications de la Mécanique Ondulatoire à l'Étude de la Structure des Molécules: Réunions d'Études et de Mises au Point, tenues sous la présidence de Louis de Broglie. Pp. 223. Éditions de la Revue d'Optique Théorique et Instrumentale, Paris. 1953. Fcs 1600 net.

The Determination of Crystal Structures, Vol. 3: The Crystalline State, by H. Lipson and W. Cochran. Pp. 345. G. Bell and Sons Limited, London. 1953. 50s. net.

General Chemistry (2nd ed.), by Linus Pauling. Pp. 710. W. H. Freeman and Company, San Francisco. 1953. 51s. net.

Industrial Inorganic Analysis, by Roland S. Young. Pp. 368. Chapman and Hall Limited, London. 1953. 36s. net.

Inorganic Syntheses, Vol. IV. Editor-in-chief John C. Bailar, Jr. Pp. 218. McGraw-Hill Book Company Inc., New York. 1953. 36s. net.

Mises au Point de Chimie Analytique Pure et Appliquée (Première Série),

edited by J. A. Gautier. Pp. 172. Masson et Cie., Paris. 1953. Fcs 1400 net.

Nature and Structure of Collagen, by J. T. Randall. Pp. 269. Butterworths Scientific Publications, London; Academic Press Inc., New York. 1953. 42s. net.

Organic Chemistry (5th ed.), by F. Sherwood Taylor. Pp. 612. William Heinemann Limited, London. 1953. 16s. net.

Organic Crystals and Molecules, by J. Monteath Robertson. Pp. 340. Cornell University Press, New York; Geoffrey Cumberlege, London. 1953. 32s. 6d. net.

Organic Syntheses, Vol. 33, edited by Charles C. Price. Pp. 115. Chapman and Hall Limited, London. 1953. 28s. net.

Physical Constants of Hydrocarbons, Vol. 5, by G. Egloff. Pp. 524. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1953. 160s. net.

Polarography (2nd ed. revised), Vols. I and II, by I. M. Kolthoff and James J. Lingane. Pp. 990. Interscience Publishers, New York and London. 1953. \$11 and \$12.50 respectively.

Starch and its Derivatives (3rd ed. revised), Vol. II, by J. A. Radley. Pp. 465. Chapman and Hall Limited, London. 1953. 65s. net.

Structure Reports for 1945-1946, Vol. 10. General editor A. J. C. Wilson. Pp. viii + 325. A. Oosthoek's Uitgevers Mij., Utrecht. 1953. Fl. 45 net.

GENERAL

Scientific American Reader. Pp. 626. Simon and Schuster, New York. 1953. \$6 net.

Some Aspects of the Conflict between Science and Religion, by H. H. Price. Pp. 54. Cambridge University Press, London. 1953. 3s. 6d. net.

GEOGRAPHY

The Climates of the Continents (4th ed.), by W. G. Kendrew. Pp. 607. Oxford University Press, London. 1953. 50s. net.

Géographie Mathématique, by Paul Rossier. Pp. 198. Société d'Éditions d'Enseignement Supérieur, Paris. 1953. Fcs 600 net.

The Physical Basis of Geography, by S. C. Chatterji. Pp. 430. Ram Narain Lal, Allahabad. 1953. 8 rupees net.

Pioneer Plant Geography, by W. B. Turill. Pp. 267. Martinus Nijhoff, The Hague. 1953. Fl. 19 net.

HISTORY OF SCIENCE

A History of the Sciences, by S. F. Mason. Pp. 520. Routledge and Kegan Paul, Limited, London. 1953. 28s. net.

The Resources of Leonardo da Vinci. Papers delivered at Southern Illinois University, 12-15th November, 1952, edited by George Kimball Plochmann. Pp. 39. Southern Illinois University, Carbondale, Illinois. 1953. \$1 net.

PHARMACOLOGY

British Veterinary Codex, 1953. Pp. 737. The Pharmaceutical Press, London. 1953. 45s. net.

Calendar of the Pharmaceutical Society of Great Britain, 1953-1954. Pp. 300. The Pharmaceutical Press, London. 1953. 12s. 6d. net.

Pharmacy and Medicine in Old Edinburgh, by G. C. Drummond. Pp. 35. The Pharmaceutical Press, London. 1953. 2s. 6d. net.

PHYSICS

Comptes Rendus du premier Congrès International de Microscopie Électronique, Paris, 1950. Pp. 768. Éditions de la Revue d'Optique Théorique et Instrumentale, Paris. 1953. Fcs 8000 net.

Electrical Breakdown of Gases, by J. M. Meek and J. D. Craggs. Pp. 507. Oxford University Press, London. 1953. 60s. net.

Experimental Nuclear Physics, Vol. II, edited by E. Segrè. Pp. 600. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1953. 96s. net.

Flow Properties of Disperse Systems, by J. J. Hermans. Pp. 445. North-Holland Publishing Company, Amsterdam. 1953. Fl. 35 net.

An Introduction to Electronics for Physiological Workers, by I. C. Whitfield. Pp. 236. Macmillan and Company Limited, London. 1953. 18s. net.

Mécanique Physique, by P. Fleury and J. P. Mathieu. Pp. 439. Éditions Eyrolles, Paris. 1953. Fcs 2900 net.

Nuclear Physics, by W. Heisenberg. Pp. 225. Methuen and Company Limited, London. 1953. 12s. 6d. net.

ZOOLOGY

Manuel de Paléontologie Animale, by Léon Moret. Pp. 759. Masson et Cie., Paris. 1953. Fcs 2880 net.

Notes on contributors

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Born at Aberdeen in 1912, and educated at King's College, Newcastle-upon-Tyne. Carried out post-graduate research work on precision high-voltage measurement and spark-gap phenomena at King's College, Newcastle, and Queen Mary College, London, with particular reference to the characteristics of the uniform-field spark-gap, for which a detailed calibration for the measurement of high alternating voltages was made. During the war he worked in a Ministry of Supply research department, and afterwards joined the Nelson Research Laboratories of the English Electric Company Limited, where he was in charge of the high-power laboratory. Appointed to the chair of electrical engineering at the Royal Technical College, Glasgow, in 1948.

T. A. STEPHENSON

D.Sc., F.R.S.,

Was born in 1898. After eight years as lecturer in zoology at University College, London, he was in 1930 appointed professor of zoology in the University of Cape Town. In 1941 he took up his present post of professor of zoology at University College, Aberystwyth. He was in charge of the section of the Great Barrier Reef Expedition (1928-9) which studied shore ecology. He has also carried out a biological survey of nearly two thousand miles of the South African coast between tidemarks. In 1946-8 and 1952 he visited North America and Bermuda in order to make further coastal surveys. He has published various papers on sea anemones, culminating in a two-volume monograph on the British species, published in 1928 and 1935; a series of papers on coral biology in the Scientific Reports of the Barrier Reef Expedition, 1931-4; and another on the South African survey. A further series, on the North American coast, is now appearing in the Journal of Ecology. His book 'Seashore Life and Pattern' was published in 1944.

ANNE STEPHENSON

After her marriage with Professor T. A. Stephenson in 1922 was trained by him to act as his research assistant. Was a member of the Great Barrier Reef Expedition of 1928-9, studying the breed-

ing of reef invertebrates; she published a report on this subject in 1934. Was her husband's chief assistant in the ecological survey of the South African coast, 1931-40. Accompanied him to the United States, Canada, and Bermuda as co-worker, and has published joint ecological papers with him.

H. S. W. MASSEY,

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Was born in 1908 and was educated at the University High School, Melbourne and Melbourne University. After graduation he undertook research work in atomic physics at the Cavendish Laboratory, Cambridge. In 1933 he was appointed head of the department of mathematical physics at Queen's University, Belfast, and in 1938 became Goldsmid professor of mathematics at University College, London. He held this chair until 1950, when he became Quain Professor and head of the department of physics at the same college. In addition to many papers and reviews in scientific journals he is joint author of the two monographs 'The Theory of Atomic Collisions' (with N. F. Mott) and 'Electronic and Ionic Impact Phenomena' (with E. H. S. Burhop), and has also written two other books.

CHARLES SINGER,

M.D., D.Litt., Hon. D.Sc., F.R.C.P.,

Was born in London in 1876 and studied at University College, London, Magdalen College, Oxford (of which he is now an Honorary Fellow), and Heidelberg. He has been lecturer in the history of biology at Oxford, professor of the history of medicine at London University, and visiting professor of the history of science at the University of California. Among his works are 'A History of Biology,' a 'Short History of Science,' and 'The Earliest Chemical Industry.' With E. J. Holmyard and A. R. Hall he is editing 'A History of Technology' in five volumes. Much of his work has been done with his wife, Dorothea Waley Singer, known for her writings on the philosophy of science, alchemy, and bibliography of early science.

JAMES KENDALL,

M.A., D.Sc., LL.D., F.R.S., P.R.S.E.,

Is professor of chemistry and Dean of the Faculty of Science in the University

of Edinburgh. He completes this year his term of office as President of the Royal Society of Edinburgh, the first chemist to hold that distinction. His interest in the aims of the Alembic Club is shown by his books 'Great Discoveries by Young Chemists'; 'Humphry Davy: "Pilot" of Penzance'; and 'Michael Faraday: Man of Simplicity,' all recently published or in course of publication. He was educated at Farnham Grammar School and the University of Edinburgh; he was a post-graduate student at Heidelberg University, the Nobel Institute, Stockholm, and the Technological Institute, St Petersburg. From 1913 to 1926 he taught at Columbia University, New York.

HERVÉ HARANT,

Docteur-ès-Sciences,

Was born at Paulhan (Hérault) in 1901 and studied at the universities of Strasbourg, Montpellier, and Paris. He became assistant in the Faculty of Science at Montpellier, and then was successively *chef de travaux* in pathological anatomy and *agrégé* of the Faculty of Medicine. He is now professor of natural history, parasitology, and exotic pathology in the Faculty of Medicine at Montpellier, and director of the botanic garden. He has published papers on marine zoology, pathological anatomy, parasitology, epidemiology, botany, and ecology.

KARL K. DARROW,

Ph.D.

Born in 1891. Undergraduate and graduate study at the University of Chicago. Since receiving his doctorate in 1917 he has been continuously with Bell Telephone Laboratories, New York, except for brief periods as visiting professor at the University of Chicago, Columbia University, Stanford University, and Smith College. His principal occupation has been writing and lecturing on physics and neighbouring sciences. His books are 'Introduction to Contemporary Physics,' 'Electrical Phenomena in Gases,' 'Renaissance of Physics,' and 'Atomic Energy.' He has published numerous papers, mostly of the character of surveys. His lectures on solid-state electronics, given at the University of London in 1953, are about to be published in *Research*. Since 1941 he has been secretary of the American Physical Society.

ENDEAVOUR

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of mankind

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The Royal Society of Arts

This year marks the bicentenary of the Royal Society of Arts, the history of which is related in a book written by Derek Hudson and Kenneth W. Luckhurst and recently published.¹ The Society was born at a time of great industrial and commercial activity, when local crafts were beginning to give ground before the advance of mechanized factories, and when 'almost every Master-Manufacturer hath a new Invention of his own, and is daily improving on those of others'. These conditions led to the founding of various technical societies for the study of trade, industry, and the industrial arts, and the Royal Society of Arts was one of the first of such associations to be established in Great Britain.

The idea of the Society was conceived by William Shipley (1714-1803), brother of the then Bishop of St Asaph and a friend of Benjamin Franklin; he was an obscure drawing-master at Northampton. In the beginning, Shipley's plan was that industry should be stimulated by prizes drawn from a fund contributed by public-spirited people, but, as so often happens, the first step towards the realization of the project was the most difficult. Full of enthusiasm, however, Shipley obtained an introduction to Stephen Hales, the distinguished author of 'Vegetable Statics', and was fortunate enough to meet with encouragement. Hales mentioned the matter to influential friends, and on 22 March, 1754, at a meeting at a coffee-house in Covent Garden, it was decided to form a society 'for the Encouragement of Arts, Manufactures and Commerce'. This title, with the addition of 'Royal' in 1908, has been the official designation of the Society ever since, though it has always been more familiarly known by the abbreviated version, 'Society of Arts'.

The Society clearly supplied a great want, for it grew with astonishing rapidity, and by 1762 had a membership of over 2500; among the earliest members were such well known figures as Thomas Chippendale, Robert Clive, Edward Gibbon, William Hogarth, Samuel Johnson, Joshua Reynolds, Samuel Richardson, and Horace Walpole.

One of the reasons for the Society's speedy rise to eminence was that, in the eighteenth century, there were no departments of state or other institutions to deal with such affairs as agriculture, forestry, trade, industrial art and science, and

many other public matters that are today the concern of various specialist bodies; moreover, public-spirited men welcomed the opportunity offered by the new society to serve their country in ways not previously envisaged.

For nearly a hundred years the Society followed Shipley's plan of 'encouragement' by offering premiums for specified purposes, and the annual prize-giving became one of the major social events of the season during the earlier part of the nineteenth century; in 1848 no less a person than the Prince Consort made the presentations. Among the Society's efforts, none was promoted more energetically than that devoted to the improvement of agriculture, where it was fortunate enough to secure the services of Arthur Young, the famous agriculturist, as chairman of its appropriate committee. It may be said with truth that the British agricultural revolution of the eighteenth century was in the main effected through the influence of the Society, which offered prizes for such objects as the improvement of agricultural machinery, the production and use of manures, better methods of cultivation, and many other aspects of what we now call agricultural science.

A related subject in which the Society took much interest was afforestation. At the time when the Society was founded there was a serious shortage of timber for fuel and shipbuilding, and the matter was one of national concern. By the offer of medals, themselves of little intrinsic value but carrying much honour, the Society induced wealthy landowners to embark upon ambitious programmes of afforestation. From 1758 to 1821 the Society awarded 127 gold medals and 40 silver medals for these activities, and the number of trees planted during this period was at least fifty million. Many of the woods in Great Britain today owe their existence to the Society of Arts.

Among early members of the Society were several distinguished chemists, and the chemistry committee was one of the most important. Then, as now, sulphuric acid and alkalis were in great demand for industrial purposes, and though Ward and Roebuck had improved methods of manufacturing the acid, greater supplies of alkali were a pressing need. The Society attempted to meet this need by encouraging the production of alkali from home vegetable sources, and by importation from the American colonies. Better success attended its efforts for the refinement of whale oil and

¹ 'The Royal Society of Arts, 1754-1954.' *John Murray, London. 1954. 30s. net.*

the manufacture of verdigris, and its far-sightedness is attested by its award, in 1808, of a silver medal to Samuel Clegg, inventor of the modern type of gas-holder and of the gas-meter, for a paper on schemes of gas-lighting in factories and public buildings. At about the same time, the Society awarded a silver medal to a Birmingham man for his coal-tar distillation process. It is worthy of note that early meetings of The Chemical Society were held in the premises of the Society of Arts.

Far-sightedness was also shown by the Society in its encouragement of art in the narrower sense of the word. Even at its first meeting the opinion was expressed that the art of drawing 'is absolutely necessary' in trade and industry, and at the next meeting the decision was taken to include prizes for drawings by children in the first list of premiums to be offered. Among the youthful prizewinners, of average age 13, were Landseer, Millais, Lawrence, and Eastlake, the last three of whom later became presidents of the Royal Academy. In 1760 the Society organized the first public exhibition of contemporary art to be held in Britain. The exhibition was a striking success, and the stimulus it provided led to the foundation of the Royal Academy only eight years afterwards.

Its experience in 1760 convinced the Society of the value of exhibitions, which have formed a principal feature of its activities throughout its life. In 1761 it staged the first British industrial exhibition, a display of agricultural machinery, but its most resounding success was the Great Exhibition of 1851. This seems to have been the personal inspiration of the Prince Consort, who was then president of the Society and who felt that the exhibition should be on international rather than national lines. The final management of the Great Exhibition was taken over by a Royal Commission, but the chief credit for it must certainly be given to the Society.

The Society soon extended its interests beyond the limits of Britain to British possessions overseas, and awards were offered to help the colonies either by encouraging the introduction there of new plants and industries, or by promoting the export of colonial produce to Britain. The famous expedition of the *Bounty* originated from the Society's offer of a prize for the successful transplanting of the bread-fruit tree to the West Indies. The commander of the *Bounty*, Captain Bligh, was not to succeed on this occasion, but on a second expedition, in the *Providence*, he successfully transplanted not only bread-fruit trees but very many other valuable plants to the West Indies; he was

awarded the Society's gold medal. Some thirty years later, in 1820, the Society offered two further gold medals, one for the largest quantity of fine wool imported from New South Wales and a second for the finest sample of wool from that colony; both were awarded in 1822 to John Macarthur, founder of the Australian wool trade which now plays so great a part in Commonwealth and international commerce. The Society also encouraged the early wine industries of South Africa and Australia, and tea cultivation in India.

Such a sweep of achievements, in so many and such diverse fields, might seem ample to satisfy the ambitions of several societies, not merely those of one; but the Society of Arts went, and goes, from strength to strength. Whatever the task, the Society has always been willing to attempt it, if its accomplishment seemed to be likely to benefit the arts, the sciences, trade and industry, education, or public health. For example, it was responsible for the abolition in Britain of the practice of sweeping chimneys by sending small boys up them, and for the introduction of the chimney-sweep's extending flue-brush; it also, in 1851, pioneered and established the system of public lavatories—one of the civic amenities that perhaps are hardly thought of as having had to be deliberately inaugurated. The Society further made possible a microscope that sold for half a guinea, and a box of paints for a shilling: eleven million of these boxes were sold between 1851 and 1870.

There are, indeed, few cultural or industrial fields in which the beneficent and beneficial influence of the Society of Arts has not been felt. The founding of the Royal College of Music and that of the Royal Photographic Society stand to its credit, and such miscellaneous affairs as the printing of bank-notes, life-saving at sea, cartography, shipbuilding, the construction of scientific instruments, the design of textile machinery, postal reform, and the supply of fresh fish to London all figure in its list of agenda. The lectures delivered under its aegis by leading authorities on their subjects cover all branches of arts, manufactures, and commerce, and are invariably well attended.

The bicentenary volume by Hudson and Luckhurst gives an absorbing account of the two hundred years of the Society's life and manifold activities, enriched by the inclusion of many illustrations. Here we have been able to give only a sketch of what is surely one of the most remarkable societies in the world. Under its present president, H.R.H. the Duke of Edinburgh, it enters its third century with undiminished vigour and confident purpose.

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The viscosity of liquids

E. N. DA C. ANDRADE

The viscous properties of liquids offer peculiar difficulties to the theoretical physicist who wishes to deduce them from the conventional laws of molecular interaction. Examination of the experimental results has, however, revealed a number of general regularities, especially where the variation of viscosity with temperature is concerned, and, in the case of the less complex liquids, some approach has been made to an explanation along simple lines.

INTRODUCTION

The liquid state, as contrasted with the gaseous state, and with the solid state in certain of its aspects, offers peculiar difficulties. The measured properties of gases, especially under conditions not too near the critical point, exhibit many simple and striking regularities which, in the main, have found a satisfactory representation in terms of the kinetic theory. Here the fact that the molecules are for the greater part of the time travelling at uniform speeds in a region where the intermolecular forces are negligible introduces great simplifications. Only encounters involving two, not more, molecules need be considered; since the relative orientation of two molecules involved in collision is random, the shape of the molecules is of little influence; when mechanical properties are in question it is generally possible to neglect the vibrations and rotations of the molecules; and when specific heats are concerned the part that they play can be taken into account. All these simplifying factors are absent when we come to consider liquids.

With solids—that is, crystalline solids—matters are simplified by the high degree of order in space of the atoms and molecules. Properties such as specific heat are independent of small faults or irregularities in the crystal structure. The mechanical behaviour, on the other hand, is an example of a class of properties known as structure-sensitive, for which local lattice irregularities have a supreme significance, involving the complication that the properties depend markedly upon the previous history of the specimen. Here liquids have an advantage, for with homogeneous liquids the constants concerned in flow are uniquely determined by the state—pressure and temperature—of the substance. Except in the relatively trivial cases of supercooling and superheating, thermodynamically unstable states do not occur. A study of the viscosity of liquids, then, seems a possible

source of significant information concerning the nature of the liquid state and, as will be seen, does reveal certain striking general regularities.

HISTORICAL

The history of viscosity as a branch of physics starts with Newton, when, in the Second Book of the *Principia*, he treats of fluids maintained in circular motion either by an infinitely long rotating cylinder or by a rotating sphere. His object was to investigate the properties of the Cartesian solar vortex of subtle fluid, which, by its motion, carried the planets round. He arrived at the conclusion '*Hinc liquet Planetas à Vorticibus corporeis non deferri*'—'Hence it is manifest that the planets are not carried round by material vortices' [1]. What is of interest here is that for the purpose of the calculation it is necessary to assume a law according to which the motion of one layer of liquid is transferred to a contiguous layer, and Newton stated as his hypothesis '*Resistentiam, quae oritur ex defectu lubricitatis partium Fluidi, caeteris paribus, proportionalem esse velocitati, qua partes Fluidi separantur ab invicem*'—'The resistance arising from the want of slipperiness in the parts of the fluid is, other things being equal, proportional to the velocity with which the parts of the liquid are separated one from another' [2]. The fluid in Newton's treatment was divided into 'innumerable' sheets of equal thickness, so that this assumption meant that the resistance to shearing motion was proportional to the velocity gradient. Liquids for which this is true are accordingly said to possess Newtonian viscosity.

Newton did not apply to real liquids the considerations that followed from his assumption, and for more than a century after the publication of the *Principia* those who dealt with the motion of fluids left out all considerations of liquid friction. At the very end of the eighteenth century and the beginning of the nineteenth, French investigators, Coulomb and Girard in particular,

carried out well-designed experiments on the resistance to motion offered by liquids, but without any attempt to analyse the movement. Navier, the founder of the modern mathematical theory of elasticity, in 1823, 136 years after Newton, restated Newton's law of fluid resistance without, apparently, any knowledge of what Newton had done, and defined, without giving it a name, a constant ϵ which is our coefficient of viscosity. It was, in particular, Stokes [3] who in 1845 created the modern theory of the motion of viscous liquids: for instance, starting with Newton's assumption he worked out in essence the flow through a cylindrical tube, the example most familiar to students of today who use capillary viscometers. Just about this time Poiseuille [4] published his classic work on the flow of liquids through tubes. He was a doctor of medicine interested in the flow of blood through capillaries, a fact which had the fortunate consequence that, so as to compare with the anatomical vessels, he used much finer tubes than his predecessors, the diameters ranging from 0.14 to 0.03 mm. He worked with distilled water and obtained experimentally the well known formula for the volume V discharged in unit time:

$$V = C \frac{p r^4}{l},$$

where C is a constant, p is the pressure difference at the two ends of the tube, r is the radius, and l is the length. He also measured systematically the variation of the volume V with the temperature, from 0° to 45° C. Poiseuille's work was of great accuracy, and marks an important stage in the development of the subject. It is, perhaps, strange that the study of viscosity should start theoretically with an interest in Descartes' hypothetical celestial medium and experimentally with an interest in the flow of blood, the macrocosm and the microcosm thus coming together in true alchemical fashion. '*Blut ist ein ganz besonderer Saft.*'

The first use of the term coefficient of viscosity that I can find is by Clerk Maxwell [5], when, in connection with his investigations into the mechanical behaviour of gases, he defines it in 1866: in 1860, discussing the same subject, he speaks of internal friction (which recalls the German *innere Reibung*) and coefficient of friction. In these slight historical notes many noteworthy names have been omitted, but something must be said of Thorpe and Rodger [6], who, in the 1890's, made a determined attack on the problem of the relationship between the viscosity of liquids and their chemical nature. Their work occupies about 350

pages in the 'Philosophical Transactions' of the Royal Society and comprises very careful determinations of the viscosities, at various temperatures, of 88 liquids of definite chemical composition, mostly organic compounds. In many cases their values are still the best available. The great weakness of the measurements is that, while the upper limit of the temperature range is somewhere near the boiling-point of each particular liquid, the lower limit is in all cases 0° C. This means that for liquids with low boiling-points the temperature range is very small, but, worse than this, as the freezing-points of the majority of the liquids are 50° C or more—in many cases 100° C or more—below 0° C, it is very seldom that reliable values of the viscosity are available in the neighbourhood of the freezing-point which, as will be argued, is a very interesting region.

Thorpe and Rodger, in their attempt to relate viscosity and chemical nature, wished to make a comparison of viscosities at what they called comparable temperatures and were faced with the question as to what were such temperatures. Influenced, no doubt, by the measurements, they selected the boiling-point, which seems unfortunate, since it is influenced so much by pressures of an order that leaves the viscosity unchanged. Having little success with viscosities at boiling-point they tried other methods of comparison, in particular of viscosities at 0.6 θ , where θ is the critical temperature of the liquid, and also of viscosities at points where the slope of the viscosity-temperature curve, $d\eta/dt$, was the same; in general, however, it cannot be claimed that they found any noteworthy regularities in their heroic onslaught on the problem.

Later, Dunstan and Thole [7], taking 20° C as a standard temperature for all liquids, found certain empirical rules for predicting the viscosity at this temperature within a homologous series, results of interest which, however, did not lead to any generalities on liquid viscosity.

VARIATION OF VISCOSITY WITH TEMPERATURE

The most striking feature of liquid viscosity is the very marked way in which it decreases with rise of temperature, whereas the viscosity of gases increases with temperature. A generality seems to be that, roughly speaking, the more complicated the liquid the greater the influence of temperature. Thus with certain glasses, in the temperature range where they behave as normal, but very viscous, liquids, a rise of 100° C diminishes the

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viscosity to 1000th or even much less; with a strong sucrose solution the viscosity falls to 1/70 when the temperature rises from 0° to 100° C; with a certain amyl alcohol to 1/18; with one of the octanes to 1/3; with bromine to 2/5; and with mercury to 5/7, for the same temperature interval. The liquid metals and monomolecular liquids in general show a comparatively small variation of viscosity with temperature: with liquid gallium a change of temperature of over 1000° C, from 80° to 1100° C, reduces the viscosity to 1/3.

When we turn to the question of a precise representation of the variation of viscosity with temperature we are met with a variety of formulae. One class of formula regards the change with temperature as entirely due to the change of volume. Typical of this class is Batschinski's formula [8]:

$$\eta = \frac{c}{v - w},$$

where c and w are constants. Here v is the specific volume and w a limiting volume at which η becomes infinite. The expression $v - w$ is called the free volume: values for it can be derived from other formulae, but the results of different methods do not agree very well. The essential objection to formulae of this type is that, as is clear from Bridgman's work [9] on the viscosity of liquids at high pressure, the viscosity is not a function of the volume alone. Thus figure 1 shows the viscosity of isoamyl alcohol against volume at two different temperatures; it will be seen that there are two well separated curves. Nevertheless, volume-dependent formulae are still occasionally advocated [10].

Thorpe and Rodger used Slotte's formula [8] $\eta = C/(1 + bt)^n$, where t is the temperature in °C and there are three constants, but did not find it very satisfactory and adopted another three constant formula. Duff [11] in 1897 quoted seven formulae which had been proposed and himself added an eighth, with four constants. After him Brillouin produced a formula with five constants, somewhat too many if we are seeking for simple regularities.

In 1930 Andrade [12] put forward the simple exponential formula

$$\eta = Be^{c/T} \dots \dots \dots (1)$$

to represent the variation of viscosity at constant pressure with temperature. This he later [15] modified to

$$\eta v^{\frac{1}{3}} = Ce^{c/T} \dots \dots \dots (2)$$

to take account of the change in volume which

accompanies change in temperature. It subsequently appeared that the simple exponential formula (1) had been put forward by de Guzman [13] in 1913: he took Kirchhoff's formula for the vapour pressure, $\log p = A - B/T - C \log T$, omitted the last term, and substituted ϕ for p . There does not seem to be any reason why the vapour pressure formula should apply to liquid viscosity and de Guzman's work never attracted attention, not being mentioned in any of the textbooks dealing especially with viscosity. The early history of the formula is discussed in a series of letters in 'Nature' [14].

Andrade [15] made a systematic comparison of formula (2) with the experimental results of Thorpe and Rodger, and others. Where the range of measurement, expressed as the ratio of the highest measured η to the lowest, was 2 or less, the agreement was, in general, everywhere within 0.3 per cent; for ranges up to 3, within 1 per cent; and even in more extended ranges the deviation seldom exceeded 2 per cent. In the case of normal propyl alcohol from -60° to 96° C, where the viscosity goes from 0.319 to 0.0047 poise, a range of 67, the largest error was 2.2 per cent. In general, it must be remembered that viscosity is not a property that has been measured to a high degree of accuracy. For the liquids in question the measurements have practically all been made with some form of capillary viscometer, where the fourth power of the radius is involved, and a somewhat uncertain end-correction, depending upon the



FIGURE 1 - The variation of viscosity of isoamyl alcohol with volume at 30° and 75° C, derived from Bridgman's high-pressure results. The graph shows $\log \eta/\eta_0$ against v , where η_0 is the viscosity at 30° and atmospheric pressure. (P. W. BRIDGMAN, 'The Physics of High Pressure,' G. Bell and Sons Limited, London.)

volume passing through per second, is also necessary. It is not only in absolute measurements that these factors are concerned, for both the radius and the end-correction change with temperature, especially the latter. Viscosities given to five significant figures are expressions of a genial optimism.

The general fit of the two-constant formula can, then, be claimed to be good for a variety of liquids, including liquid metals, alkyl and alkenyl halides, thioethers, primary and secondary alcohols, esters, aromatic hydrocarbons, and fatty acids. Exceptional liquids are water—of course—and tertiary alcohols, which are anomalous in other respects. It looks as if water behaves normally above 70° [12], but the range of measurements at present available is not large enough for a definite decision.

The formula $\eta = Be^{b/T}$ is widely used to represent the variation of viscosity, since it is very simple to apply. Formula (2) gives, in general, a slightly better fit when the range of viscosity is large, but the best evidence for its validity is offered by the viscosity of the series of liquid alkali metals, considered later.

GENERAL THEORETICAL CONSIDERATIONS

The exponential formula, being valid for such a wide range of liquids, in many cases with molecules of considerable complexity, seems unlikely to depend upon any particular assumption as to details of intermolecular forces. The point of view on which it was based when originally put forward is not, perhaps, unexceptionable, but it led to formulae which have had success in representing experiment, and this is one justification of hypothesis.

The molecules were regarded as vibrating, as a whole, with a fundamental frequency ν , each about an equilibrium position that moved only slowly. With a monomolecular solid, such as lead, there are various ways of estimating ν , which agree in giving a value about 2.0×10^{12} for this element. The change of volume of a metal on melting being comparatively small, the molecular forces cannot be very different in the two states at the melting-point, at any rate for elements of cubic, or nearly cubic, crystal structure, and so the frequencies must be much the same. From the coefficient of self-diffusion, measured by the help of radioactive isotopes, it appears that for an atom of liquid lead to diffuse through a distance σ , where σ^3 is the average volume of liquid per atom, the time required is about 80 periods of vibration,

which offers justification for the assumption of a quasi-stationary centre of vibration. It was assumed, without any detailed dynamical justification, that, at the melting-point, momentum was communicated from layer to layer of the sheared liquid at every extreme libration of the oscillation. From such an assumption it follows at once that η_M , the viscosity at the melting-point temperature is:

$$\eta_M = C \frac{vm}{\sigma},$$

where m is the mass of the molecule and C is a constant which must be about 1. Even with gases the constant in the viscosity formula cannot be precisely calculated except for the simplest molecules. The value $4/3$ was, by a rough argument, taken for C .

There are two general ways of finding ν for monomolecular substances, such as liquid metals and noble gases, which are particularly suitable for numerical check on a simple theory. It can be expressed as $\nu = k\theta/h$, where θ is Debye's characteristic temperature, or, by a formula due to Lindemann (Lord Chervell), as:

$$\nu = K \sqrt{\frac{T_M}{AV^{\frac{1}{3}}}},$$

where T_M is the melting-point in degrees absolute, A the atomic weight, and V the atomic volume, K having the value 3.1×10^{12} . Accordingly the viscosity of a monomolecular liquid at the melting-point is given by

$$\eta_M = \frac{4}{3} \left(\frac{A^2 \rho_M}{N^2} \right)^{\frac{1}{2}} \frac{k}{h} \theta = 3.90 \times 10^{-6} \theta \rho_M^{\frac{1}{2}} A^{\frac{1}{2}} \dots (3)$$

$$\text{or} \quad \eta_M = 5.7 \times 10^{-4} (AT_M)^{\frac{1}{2}} V^{-\frac{1}{2}} \dots (4)$$

The constant is in neither case arbitrary: 3.90×10^{-6} is the value of $\frac{1}{2}k/N^{\frac{1}{2}}h$, and 5.7×10^{-4} is the value of $\frac{1}{2}KN^{-\frac{1}{2}}$.

The values given by these formulae are in good agreement with the measured viscosity of monomolecular liquids at the melting-point. For instance, according to (3), the value of

$$\frac{\eta_M}{\theta \rho_M^{\frac{1}{2}} A^{\frac{1}{2}}}$$

should be 3.90×10^{-6} for all metals. For seven metals, Li, Na, K, Cu, Ag, Au, Pb, for which values of θ are available, the values prove to be 4.05, 4.35, 3.95, 4.05, 3.78, 3.68, 4.11, all $\times 10^{-6}$, although the extreme viscosities are as 1 to 10 and

the extreme densities as 1 to 34. For liquid helium I, the 'normal' form, the viscosity of which is about a thousandth of that of liquid gold, the available value of η gives $\eta_M = 9.5 \times 10^{-5}$ poise as against 7.3×10^{-5} found experimentally by Tjerkstra on the melting curve [16].

In figure 2 are shown the viscosities of sixteen liquid metals and of liquid argon at the melting-point, plotted against $(AT_M)^{\frac{1}{2}} V^{-\frac{1}{3}}$. It will be seen that the points lie well on a straight line, of slope 5.7×10^{-4} , with the exception of the three metals Sb, Bi, and Ga. That these metals depart from the law is, in a way, extremely satisfactory, for they are of anomalous, far from cubic, crystal structure and, in general, freakish. For instance, the ratio of the electrical conductivity in the solid state to that in the liquid state, at the melting-point, is round about 0.5 for these three, whereas for the normal metals it has values between 1.45 and 2.28. Theory gives values for these normal metals which are in quite good agreement with experiment, but for the abnormal three it predicts values in the neighbourhood of 5, that is, about ten times too big [17]. The coefficient of thermal expansion likewise shows a very marked anomaly for the three metals.

The satisfactory agreement in absolute magnitude of observed and calculated viscosity indicates that no theory based on the communication of

momentum by actual passage of the molecule from layer to layer (as in the case of gases) can be valid, for the example of liquid lead, already cited, shows that if this were the mechanism the calculated viscosity would be about a hundredth of the observed value.

To derive the temperature variation, reliance was placed on a general argument that the temperature agitation must interfere with the communication of momentum, a certain energy of orientation, or activation, being, in accordance with Boltzmann's principle, favourable for this communication. The ratio of the number of molecules possessing the required energy E at temperature T to that at T_1 must then be

$$e^{\frac{E}{k} \left(\frac{1}{T} - \frac{1}{T_1} \right)}$$

so that

$$\eta = \eta_{T_1} e^{-E/kT_1} e^{E/kT}.$$

If T_1 is the melting-point T_M , then

$$\begin{aligned} \eta &= \eta_M e^{-E/kT_M} e^{E/kT} \\ &= B e^{E/kT} = B e^{b/T}. \end{aligned}$$

If we take into account the expansion which takes place when the liquid is heated, there are three effects to be considered: the number of molecules per unit area of the plane of shear decreases, the distance between two molecular layers increases, and the mutual potential energy decreases. The average potential energy of a molecule varies, by the Van der Waals equation, inversely as v , the specific volume. If we make our viscous 'activation' energy vary in this way we get for the formula for temperature variation:

$$\eta v^{\frac{1}{3}} = C e^{E/kT} = C e^{c/vT},$$

which has been proved generally successful.

The strongest experimental argument that this gives a better representation of the mechanism than the simple exponential formula (1) is provided by the liquid alkali metals [18]. Both formulae give a good representation of the variation of viscosity with temperature for each individual metal, thus providing values of the exponential constants b and c . However, whereas c diminishes smoothly with increasing atomic weight, b shows a very irregular behaviour (figure 3). The values of the multiplying constants B and C also indicate that (4) is the preferable formula.

If we consider monomolecular liquids, and use formula (4) for η_M , we get:

$$\eta = 1.33 e^{-C/v_M T_M} \frac{\sigma_M}{\sigma} \frac{m v_M}{\sigma_M} e^{c/v T},$$

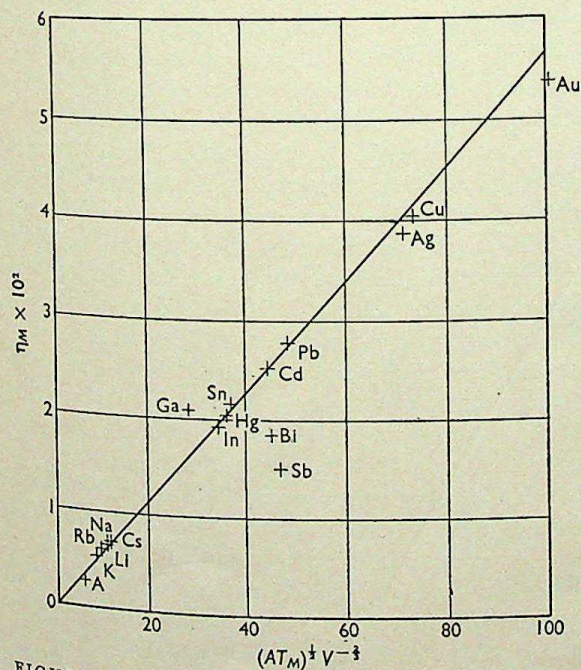


FIGURE 2 - Viscosity of liquid metals at the melting-point against $(AT_M)^{\frac{1}{2}} V^{-\frac{1}{3}}$. The point for liquid argon is also shown.

which compares with the formula derived by Born and Green [19]:

$$\eta \sim \frac{\pi^2}{315} (42\pi)^{\frac{1}{2}} \left(\frac{\sigma_M}{\sigma}\right)^5 \frac{mv_M}{\sigma_M} e^{-\phi(v)/kT},$$

the chief difference being that σ_M/σ appears to the fifth power in this formula and the more general $\phi(v)$, which cannot be used for numerical calculation, replaces v^{-1} .

KINETIC THEORIES OF THE LIQUID STATE

Something should here be said about certain recent theoretical developments. The strict mathematical theory of the liquid state aims at deducing the properties of liquids from a molecular mechanism, in particular from the potential $\phi(r)$ of mutual interaction between the molecules and from their distribution. In the case of the so-called transport phenomena, viscosity and thermal conductivity, an essential consideration is the distortion of the equilibrium distribution, a distortion produced by the velocity gradient in the case of viscosity and, less seriously, by the temperature gradient in the case of thermal conductivity. The problem has been handled, in particular, by Kirkwood, by Eisenschitz, and by Born and Green [20]. Kirkwood, starting from fundamental considerations, has simplified matters by the useful and ingenious assumption that the forces on a molecule at different instants are statistically independent, provided that the time interval between the instants is not too small, but he has not established any relation between viscosity and temperature. Eisenschitz has modified the theory of Brownian motion so as to make it apply to a single molecule and is met, of course, by the difficulty as to what is the friction constant (or rather as to what are the friction constants, for he points out that there are two), a matter with which Kirkwood has also dealt. Born and Green have developed an imposing theory based on distribution functions, which is not always easy to follow, especially in the matter of the assumptions made in dealing with viscosity.

Eisenschitz, and Born and Green, arrive at an exponential function for the variation of viscosity with temperature. The work of Eisenschitz leads to the conclusion that there is no such exponential factor in the thermal conductivity, but some relatively slowly varying function, which is in accord with experiment. None of those, however, approaching the matter from fundamental considerations of the type indicated has been able to produce results that can be checked quantitatively by

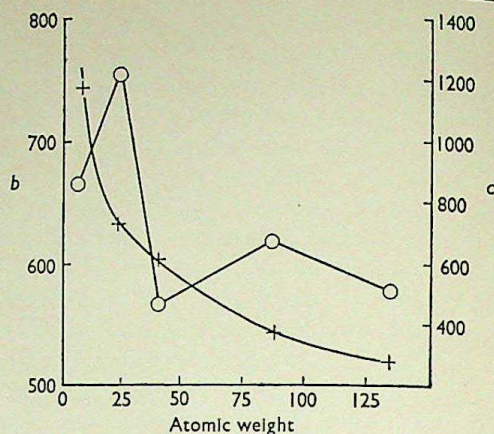


FIGURE 3 - The constants b , represented by circles, and c , represented by crosses, against atomic weight for the five alkali metals: b varies irregularly, c smoothly. (Proc. roy. Soc. A, 215, 40, 1952.)

experiment. In fact, Born and Green say specifically 'No attempt will be made to obtain exact numerical values for physical constants, as this will require extended and tedious calculations.'

A different point of view is adopted by Eyring and his collaborators in a more specialized theoretical development [21]. They consider viscous flow as a type of chemical reaction, such as takes place in a gaseous reaction or in a dilute solution, which, at first sight at any rate, it would not appear to be. The assumption of 'holes' in the liquid plays an essential part in this work. Fürth likewise considers a liquid as containing holes, outside which is a continuum with the normal surface tension; the lifetime of the holes he regards as being governed by evaporation into them, a somewhat difficult assumption considering the size of the holes.

This is not the place to attempt any adequate consideration of these theories, to which so much ingenuity and such mathematical accomplishment have been variously devoted. The difficulty of establishing a theory of viscosity upon an unexceptionable physical and mathematical base being freely acknowledged, it may be said without disrespect that none of the elaborate investigations has led to any simple quantitative relation connecting viscosity with other constants and that, in view of its very wide validity, it seems unlikely that the temperature formulae (2) or (1) can be dependent upon the existence of central, spherically symmetrical forces between molecules in equilibrium. Some very general principle, widely independent of molecular species, must, it would appear, be involved.

VISCOSITY AND CHEMICAL CONSTITUTION

The use of the exponential formula (2), with two constants C and c , seems to offer a better opportunity of connecting viscosity with chemical constitution than the older methods in which viscosities at temperatures largely arbitrary had to be selected for comparison. The constant c represents an energy which should vary systematically within homologous series of organic compounds. As regards the melting-point viscosity, it has been already shown that, for monomolecular liquids:

$$\beta = \frac{\eta_M}{\alpha} = 5.7 \times 10^{-4},$$

where $\alpha = (AT_M)^{\frac{1}{2}} V^{-\frac{1}{3}}$.

This is not to be expected to hold for any but monomolecular liquids, since it depends upon a formula for a fundamental frequency based upon very simple conceptions. At the same time it seems possible that the value of β —derived from the melting-point viscosity, the molecular weight A , and the molecular volume V —may be an important characteristic of the molecule. Methods of communication of momentum other than, and additional to, the vibrations of the molecule as a whole can only add to the viscosity, so that β should have the least value for monomolecular liquids. This is found to be so.

It has turned out that for certain molecules of similar structure and high symmetry the value of β is about the same [22]. Thus for CH_4 , CCl_4 , and SiCl_4 , $\beta \times 10^4$ is about 20, and is nearly the same for CHCl_3 and CHBr_3 . For the liquid halogens it is about 10. For molecules which depart greatly from central symmetry β increases rapidly and systematically with the asymmetry—for instance, in the case of the phenyl halides with increasing atomic weight of the halogens, and in the case of the paraffins with increasing number of carbons. In general, as has been mentioned, reliable values of melting-point viscosity are not available. It would be interesting to make a systematic examination of the values of β . It may be mentioned that for fused halides of the alkali metals, which should behave mechanically much as monomolecular liquids, the value of $\beta \times 10^4$ comes out as 6 if the average atomic weight of the two ions be taken for A .

It is found that, as far as measurements are available, the constant c varies systematically within homologous series. It is much to be desired that extended measurements with really pure organic substances should be made. Examples of

the value of c , obtained by fitting formula (2) to Thorpe and Rodger's measurements, supplemented in certain cases, are shown: figure 4a gives c for some methyl, ethyl, and propyl esters and for certain double ethers. Figure 4b is for certain chlorides, bromides, and iodides. The regularity is clear and may suffice to indicate the chemical possibilities of a systematic study of liquid viscosities.

The quantity kc/v is an energy involved in the viscous transfer of momentum, derived on the assumption that this energy is proportional to $1/v$. Debye, assuming that the Van der Waals cohesion forces are due to polarization effects produced by one molecule on another, has shown that the energy E_F per molecule due to the intermolecular field is:

$$E_F = \frac{2}{NW} \frac{a}{v},$$

where W is the molecular weight.

It seems probable that the two energies may be closely connected [15], which means that c should be related to $a_0 = 2a/NWk$. Figure 5 shows c against a_0 for a collection of the typical organic liquids used by Thorpe and Rodger. It will be seen that, in general, there is a tolerable straight-line relationship, except for the alcohols, which are associated. It is clear that the effect of rising temperature will be to diminish association in these cases and thus to make the viscosity decrease abnormally, which means that c will be abnormally large, as observed.

Some years later Roseveare, Powell, and Eyring [21] showed that the energy $\Delta F^\ddagger$, the exponent in the viscosity-temperature formula being in their

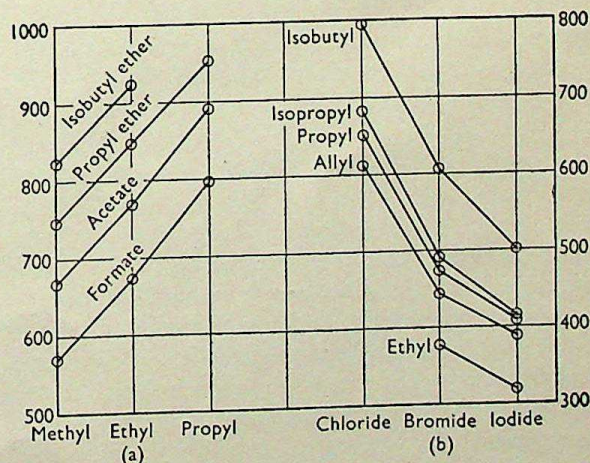


FIGURE 4—Variation of the constant c (plotted as ordinate) with chemical composition: (a) for certain esters and double ethers, (b) for certain halogen derivations.

notation $\Delta F^\ddagger/RT$, stands in a roughly linear relation to the energy of vaporization ΔE for a collection of organic liquids (figure 6). The energy of vaporization includes, of course, an external work term. It has been shown that the ratio of the internal latent heat to the Van der Waals factor a/v is reasonably constant [15], so that this confirms the close connection between the viscous energy term and the potential energy of the molecule due to intermolecular forces in a liquid in equilibrium.

EFFECT OF PRESSURE ON VISCOSITY

The work of Bridgman [9] has shown that the viscosity of all liquids¹ increases with pressure. For typical organic liquids the viscosity at 1000 atmospheres is two or three times the viscosity at normal pressure, but at the highest pressures the increase is very much more marked, the viscosity of isobutyl alcohol at 12 000 atmospheres, for instance, being 790 times normal. With mercury, the only monatomic liquid for which measurements are available, the effect is small, η at 20°C going nearly linearly from 0.0152 to 0.0201 when the pressure goes from 1 to 12 000 atmospheres. With water at temperatures below 30° the behaviour is, as noted, highly anomalous, but at 75° the viscosity steadily increases with pressure until at 9000 atmospheres it is 2.2 times normal, likewise an abnormally small effect.

The simple theory allows us to make an estimate of the increase of viscosity with pressure [15]. The frequency of vibration at high pressure comes out to be:

$$v = GV^{\frac{1}{3}} \kappa^{-\frac{1}{3}},$$

where G is a constant, V the atomic volume, and κ the adiabatic compressibility, from which follows:

$$\frac{\eta_p}{\eta_1} = \left(\frac{V_1}{V_p}\right)^{\frac{1}{3}} \left(\frac{\kappa_1}{\kappa_p}\right)^{\frac{1}{3}} e^{\frac{c}{T} \left(\frac{1}{V_p} - \frac{1}{V_1}\right)} \dots (5)$$

where suffix p denotes at high pressure and 1 denotes at one atmosphere. There are no data for adiabatic compressibility, but for liquids the ratio of the isothermal compressibilities will not differ much from the ratio of the adiabatic compressibilities and may be taken in its place.

With the only monatomic liquid available, mercury, formula (5) gives at 20°C for η_p/η_1 , when $p = 12\ 000$ atmospheres, the value 1.32, which is

¹ With the exception of water at temperatures below 30°. Water at these temperatures is, of course, very abnormal.

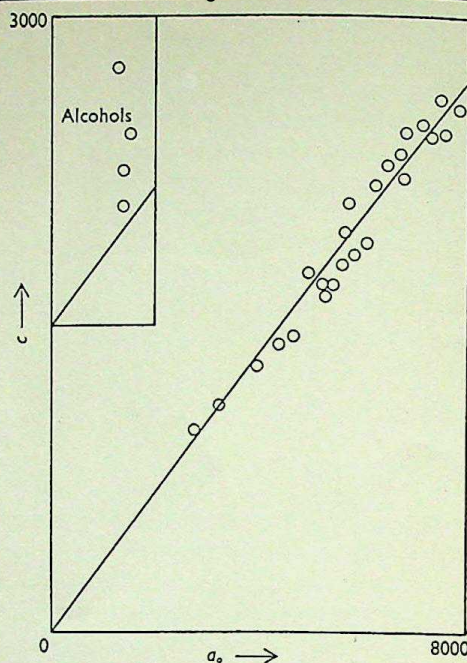


FIGURE 5 - Viscous energy constant $c = E_{vis} v/k$ against $E_{mol} v/k$, when E_{mol} is the intermolecular energy due to Van der Waals forces. (Phil. Mag., 17, 719, 1934.)

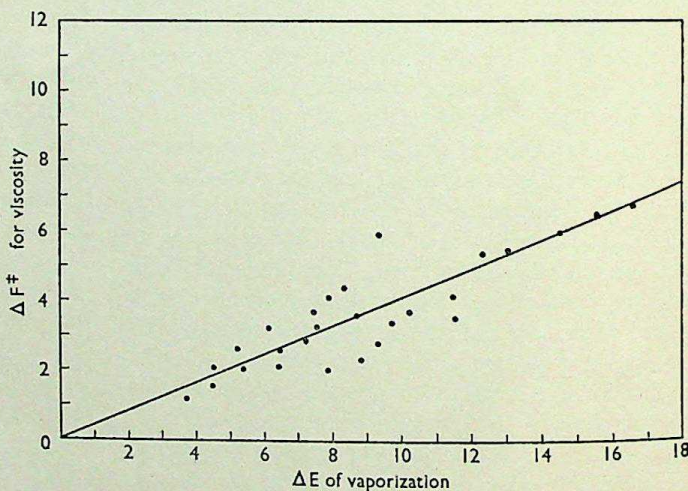


FIGURE 6 - Eyring's $\Delta F^\ddagger$, $\Delta F^\ddagger/RT$ being the exponent in the viscosity formula, against energy of vaporization ΔE . (J. appl. Phys., 12, 675, 1941.)

just the experimental value. As typical of the results with normal organic liquids we may take those exhibited in figure 7, where η_p/η_1 is shown against pressure for four liquids. In considering these results it must be borne in mind that in (5) there is no arbitrary constant available for adjustment, so that the agreement up to pressures of 2000 atmospheres is not bad. Above 2000 atmospheres the experimental η increases very rapidly,

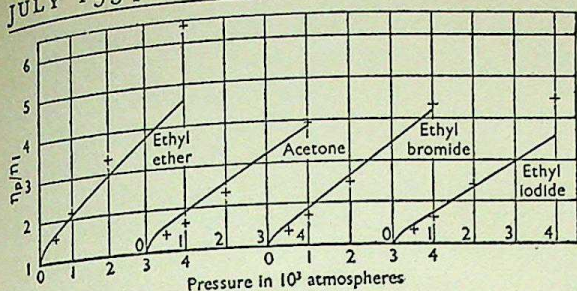


FIGURE 7 - Relative viscosity η_p/η_1 against pressure. The curves shown are calculated from formula (5); the crosses are Bridgman's observed values.

particularly so in the case of ether. Bridgman has shown that $(d^2v/dT^2)_p$ changes sign at a certain pressure, which is usually near 3000 atmospheres. This he puts down to the abolition of molecular interspace, higher pressures badly deforming the molecules. The formula, then, fails just when the conditions postulated are far from being fulfilled, and the departure is in the sense to be expected.

NEW EFFECTS WITH POLAR LIQUIDS

It has long been thought that an electric field might affect the viscosity of a liquid, and attempts to measure such an influence go back to König, who in 1885, with a crude apparatus, could detect no change of viscosity with carbon disulphide. A number of workers who devoted attention to the subject during the following fifty years or so agreed in finding no effect of an electric field on the viscosity of non-polar liquids, such as benzene and carbon tetrachloride, but recorded positive effects, of very varying magnitude, with polar liquids. With one and the same liquid different investigations yielded very discordant results, both as to the magnitude of the effect and its variation with field strength. In some cases increases of viscosity of 100 per cent, and even more, were recorded.

The problem was attacked again by Andrade and Dodd [23], who found that there was no change of viscosity to within 1 part in 100 000 with non-polar liquids, even with fields of 42 kV/cm, and further that all the large changes of viscosity recorded previously with polar liquids were spurious. All polar liquids conduct electricity to some extent, which leads to an accumulation of ions in the neighbourhood of the electrodes between which the liquid flows. These ions act as centres round which polar molecules cluster, leading to an increase of viscosity which is capricious, since it depends on the distance between the electrodes and other trivial factors. If, instead of a steady field, an alternating field is used, the effect

decreases with increasing frequency until it becomes so small that it cannot be detected without special precautions.

If, however, very accurate methods of timing and very careful control of temperature are used, there is a small genuine increase of viscosity of polar liquids with field; this has to be measured with alternating fields of frequency in the region of 10 000 c/sec. It has been established that:

$$\frac{\Delta\eta}{\eta} = fF^2,$$

where $\Delta\eta$ is the increase of viscosity due to field, and f is a constant to which the name viscoelectric has been given. If the field is measured in e.s.u., f is in the neighbourhood of 2×10^{-7} . The smallness of the effect can be judged by the fact that, with the highest practicable field, the greatest value of $\Delta\eta/\eta$ is about 0.0012.

A general explanation of the effect can be found along the lines that any directional effect, such as that of the field, will tend to check the ordered rotation of the molecules which is a consequence of laminar flow. The present state of the theory of liquid viscosity does not allow a precise calculation of the effect, which remains for mathematicians to use as a touchstone for their theories.

Another new effect, established by Dodd and Hu Pak Mi [24], concerns the viscosity of super-cooled liquids. Here again the effect has been established for polar liquids only. The nature of the effect is clear from figure 8, in which $\log \eta$ is plotted against $1/T$ for phenyl ether, which has the convenient melting-point of 26.85°C ($1/T_M = 0.003335$). It will be seen that the plot is represented by two straight lines, intersecting at the melting-point. This is established beyond question by fitting a straight line to the points above the melting-point and then plotting deviations from this line, as shown in the inset. The melting-point found from the intersection is 26.95°C . The effect was established for other polar liquids, in particular by Hu Pak Mi for phenyl salicylate and menthol. It has since been found by Greenwood and Martin [25] for certain boron trifluoride compounds.

There is no measurable discontinuity of density at the melting-point, but Dodd and Roberts [26] have found with polar compounds a discontinuity in the variation of dielectric constant with temperature similar to that which exists for viscosity. The cause of the increase of viscosity has not been established, but it may possibly be attributed to the fluctuating formation of small, unstable

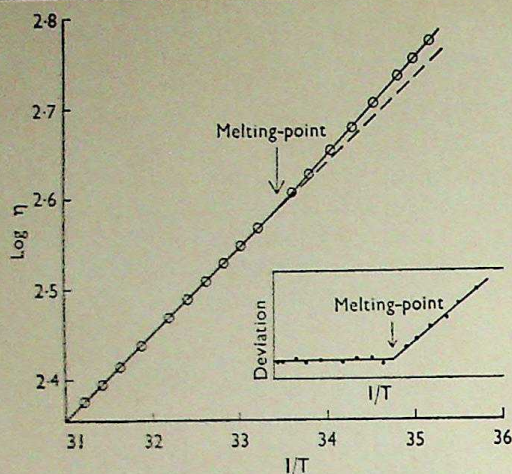


FIGURE 8 - $\log \eta$ against $1/T$ for phenyl ether in normal and supercooled states, showing discontinuity at melting-point. (DODD and HU PAK MI. Proc. phys. Soc. B, 62, 457.)

crystalline nuclei at temperatures below the melting-point. A careful study of the effect may throw light on the mechanism of melting.

Both the viscoelectric effect and the supercooling effect show for the first time that a difference between polar and non-polar liquids can be established by viscosity measurements.

NON-HOMOGENEOUS LIQUIDS

The class of suspensions known as lyophobic, or solution-hating, consists of liquids containing dispersed particles so small that they are kept from settling by Brownian motion. The pink gold sols are typical lyophobic suspensions, with the characteristic property that the addition of a very small amount of electrolyte will lead to irreversible coagulation. The viscosity of a suspension of spheres was worked out by Einstein on purely hydrodynamic grounds. He found that:

$$\eta = \eta_0(1 + 2.5\phi),$$

where η_0 is the viscosity of the pure liquid and ϕ is the total volume of the spheres in unit volume of liquid, which, surprisingly enough, is the only factor concerned in dilute suspensions of this kind. The formula has been extended for more concentrated suspensions by adding a term in ϕ^2 . The properties of such suspensions are, then, explicable in terms of classical hydrodynamics, and their study does not in any way help to explain the nature of liquid viscosity.

The viscosity of suspensions of rod-like particles has attracted particular attention on account of the way in which Staudinger utilized it to find

the molecular weight of high polymers. The mathematical problem was attacked by G. B. Jeffery, who substituted ellipsoids for Einstein's spheres and obtained Einstein's formula with, in place of the constant 2.5, a coefficient which was a function of the ratio $f = a/b$, where a and b are, respectively, the major and minor axes of the ellipsoid of rotation. Jeffery, like Einstein, did not take account of the Brownian motion. Eizenschitz [27] showed that different expressions involving the form factor f were involved in the case of Brownian motion and in that of no Brownian motion, but in both cases his formulae showed a viscosity proportional to the concentration. Experiment showed that this is not so except for small concentrations, and the longer the particles the smaller the limiting concentration for validity, which might be expected. At higher concentrations the viscosity increases much faster than the concentration, especially with very long particles. Staudinger assumed that the viscosity was proportional to the molecular weight for his dilute solutions of polymers, according to the formula:

$$\eta_s = \frac{\eta - \eta_0}{\eta_0} = KM_c,$$

where M is molecular weight, c concentration, and K a constant characteristic of the polymer. J. M. Burgers [28] and others have criticized this assumption: it appears that there is a rough proportionality to molecular weight over a limiting range only, and that, in any case, the assumption of rod-like molecules cannot be valid for the suspensions concerned. The long molecules must be crumpled or coiled. The question is clearly a very complicated one, but Staudinger's investigations have brought it into prominence.

There are still more troublesome problems when we turn to the other class of suspensions, the lyophilic suspensions or gels. The exact definition of a gel is not a question on which we choose to linger. Typical of the class are dilute solutions of gelatine or agar. Whereas the lyophobic solutions are characterized by a Newtonian viscosity the lyophilic are not, the shearing stress increasing faster than the shearing strain. A further difficulty is presented by certain colloidal substances, of which paints are typical. Here the viscosity is a function not only of the rate of strain, but also of the previous history of the substance. A stirred paint—say a suspension of 30 per cent of lithopone in a liquid medium—flows freely if freshly stirred, but becomes progressively immobile on standing, although the state of easy flow

can always be restored by stirring. This is the familiar phenomenon of thixotropy, as Freundlich called it. With such substances we approach the difficulties that meet us when we have to consider the flow of the solid state. In general, the problems presented by the viscosity of suspensions, other than dilute ones of insoluble particles of simple shape, are very difficult, and many of them have not even been mentioned here.

CONCLUSION

The field of present-day research on liquid viscosity ranges, then, from the simplest monomolecular liquids, such as liquid sodium and argon, where the assumption of spherically symmetrical molecules can be justified, through more complicated monomolecular liquids, such as liquid gallium, where it undoubtedly can not, to a large class of liquids of varying molecular complexity, which all show Newtonian viscosity and are sub-

ject to a simple law of temperature variation. Among liquids of relatively simple molecular structure are abnormal liquids, such as water, where a varying association leads to peculiar difficulties. Suspensions extend the range of properties into fields of non-Newtonian viscosity, the more complicated ones leading us into regions where, as with solids, the flow properties are not solely determined by the temperature and pressure, but depend upon past history. Of certain fields, such as the viscosity of solutions, nothing has been said. From the theoretical point of view little has been done, except in the case of the simplest liquids, to account quantitatively for viscous properties or to connect them with other liquid characteristics. It would seem that the time is ripe for a new method of approach by such among the younger mathematical physicists as can muster interest in a very old problem, the liquid state.

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The Amsterdam Historical Medical-Pharmaceutical Museum

D. A. WITTOP KONING

Amsterdam is fortunate in possessing an authentic reconstruction of an early nineteenth-century pharmaceutical laboratory, fitted out with the actual contents of the original laboratory. This forms the nucleus of the Historical Medical-Pharmaceutical Museum, here described by the curator, Dr Wittop Koning. The Museum is particularly noted for its large collection of Delft-ware pharmacy pots, some of which are of great artistic merit.

With the decline of alchemy in the seventeenth and eighteenth centuries, practical chemical investigations tended to pass more and more into the hands of the apothecaries, many of whom were also physicians. In England, it is true, few of these pharmaceutical workers attained much eminence, though the names of George Starkey, George Wilson, John Quincy, and William Lewis are familiar to historians of chemistry. English chemistry of the time was advanced mostly by gifted amateurs, such as the leisured aristocrats Robert Boyle and Henry Cavendish, and the theologian and pamphleteer Joseph Priestley; the only professional British chemists of equal stature were John Dalton and Joseph Black. On the continent of Europe, however, the part played by apothecaries in the development of chemistry was considerable, as witness the names of Glauber, Lémery, Scheele, Sertürner, Pelletier, and Caventou.

Glauber (1604-70) was the first to describe the preparation of spirit of salt from salt and oil of vitriol; the sodium sulphate obtained in the same operation is still popularly known as Glauber's salt. He had an inkling of the relation between acids, bases, and salts, and foreshadowed later ideas on affinity and chemical bonds. Lémery (1645-1715), court apothecary to Louis XIV of France, wrote a celebrated text-book of practical chemistry, *Cours de Chimie*, which was first published in 1675 and afterwards appeared in many editions and in many languages. Scheele (1742-86), a Swedish apothecary, discovered oxygen, chlorine, hydrogen fluoride, glycerol, and numerous organic acids. Sertürner (1783-1841) discovered morphine, which he isolated from opium; Pelletier (1788-1842) and Caventou (1785-1878) discovered quinine, strychnine, brucine, and cinchonine, and in 1819 invented the word chlorophyll.

To this list of apothecary-chemists many other names could be added, but those mentioned are sufficient to show how largely chemistry was indebted to the pharmaceutical laboratory in the period immediately preceding the birth of the modern science. It is therefore a matter of much interest that practically the whole of the contents of an early nineteenth-century Dutch apothecary's laboratory has been preserved and is now housed at Amsterdam in a reconstruction of the laboratory itself. This forms one of the exhibits in the Historical Medical-Pharmaceutical Museum in the Guildhall of the Vintners, the only one of the original guildhalls of Amsterdam to survive.

The pharmacist was Anthoni d'Ailly (1766-1825), who took over from T. P. Schonk a laboratory that had been established in 1776. He soon began to produce numerous drugs on a manufacturing scale, and we owe the preservation of his laboratory to the fact that from it grew a flourishing business in chemicals and pharmaceuticals still in existence. d'Ailly's grandson, indeed, assisted C. E. Daniëls, the founder of the Museum, to arrange the pharmaceutical section. The reconstruction of the laboratory in 1902 was given verisimilitude by careful reference to two water-colours of it (one is reproduced in figure 2) painted in 1818 by J. Jelgerhuis; noteworthy are the beautiful panelled ceiling and the masonry furnace, which capture the atmosphere of the period. It may be added that the reconstruction and arrangement of the laboratory have been so carefully carried out that it is more than a museum piece: if necessary, practical operations could be started in it at any moment without further preparation.

Anthoni d'Ailly's empty right sleeve (figure 1) is witness to the fact that he was an experimenter: on 17th January 1809 he lost an arm through an explosion of silver fulminate. However, he soon



FIGURE 1 — *Anthoni d'Ailly.*

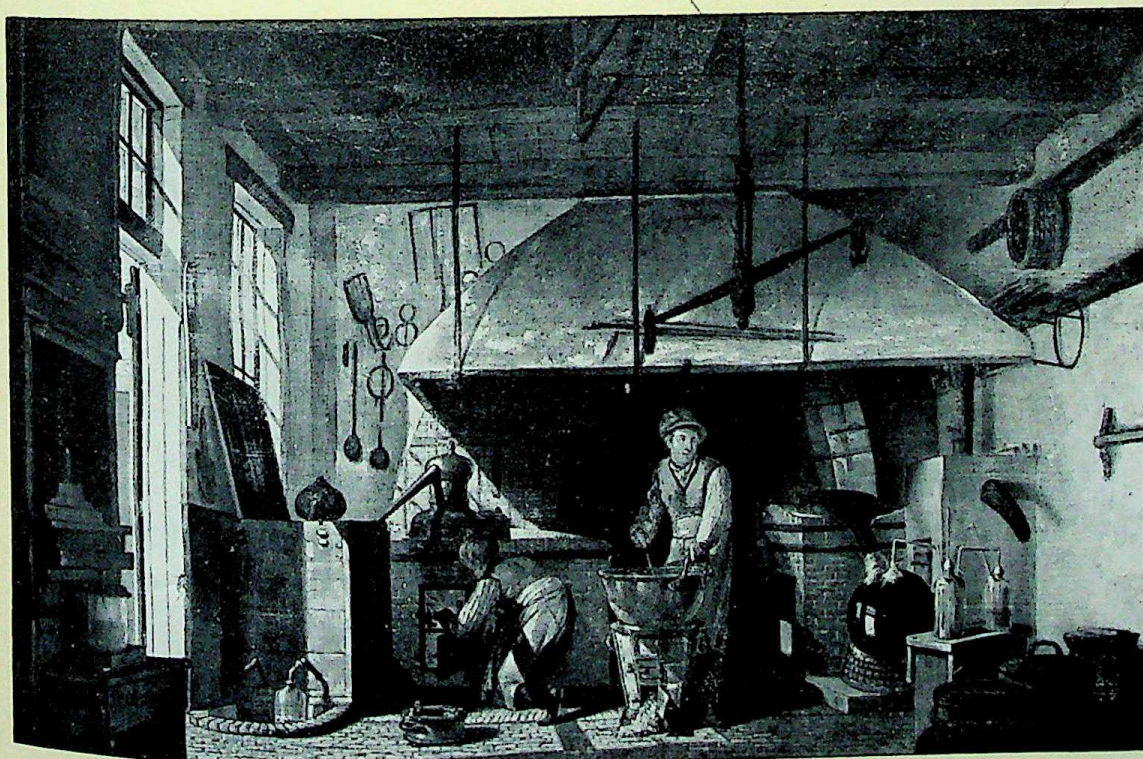
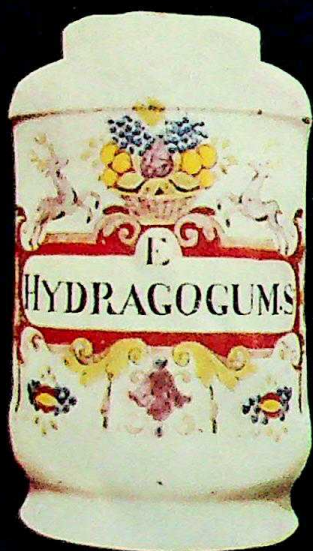


FIGURE 2 — *Water-colour painting of d'Ailly's laboratory, by J. Jelgerhuis.*



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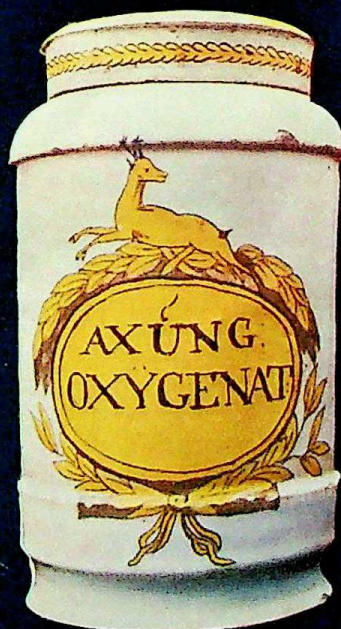
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FIGURE 10 - A mortar cast by Conradus Splinter in 1645.

became primarily a business man, and a ledger covering the years 1819 and 1820 gives information about his considerable output and numerous clients; from this ledger the author compiled a price-list of d'Ailly's products and the quantities that he sold during these years. The data are important for the study of the cost of pharmaceuticals, an illuminating aspect of the history of pharmacy that has received close attention in Germany.

After d'Ailly's death, his two sons continued the business, and one of them, A. J. d'Ailly (1793-1851), became well known for his scientific work. He was, for example, the first apothecary to become a member of the commission for the Dutch Pharmacopoeia, and helped to compile the 1851 edition; all the other members of the commission were physicians. Anthoni's son-in-law, also a partner in the firm, was the first to prepare quinine from Javanese cinchona, and thus secured for Amsterdam the market in the Javanese bark.

Of the objects in the laboratory, perhaps the most outstanding is a large plate of Chinese porcelain used for the evaporation of extracts. This use may seem a strange one, but porcelain is exposed to much higher temperatures during manufacture than is common pottery and is thus better suited for withstanding heat when used for inspissation. The balances in the laboratory are of interest; one of them contains a number of seals that have allowed the reconstruction of the series of year-seals of the Dutch inspectors of weights and measures [1].

Besides the laboratory there is a pharmacy (figure 3) with Louis XVI panels, acquired by the Museum from another pharmacy now demolished. This panelling admirably sets off the large collection of Delft-blue pharmacy pots, which is the finest in the world and particularly interesting for its great variety in designs and potters' marks. The name Delft-ware is given to pottery covered internally and externally with a layer of tin glaze, in contrast to the older majolica which has a transparent lead glaze; it is made not only at Delft but, for example, at Lambeth (London) and in France and Belgium.

Besides the Delft-blue pots in the Museum there are some polychrome specimens; these deserve special attention, as they are very scarce (figures 4-9). Figure 4 shows a cylindrical pot with the inscription E HYDRAGOGUM. s.; it is decorated with a variant of the famous peacock motif, showing deer instead of peacocks, and is unmarked. Figure 5 is of a cylindrical pot belonging to a series of three. It is inscribed E LENTIV: L: and



FIGURE 11 - A 'gaper', or sign of an apothecary's shop.

is decorated with a reclining deer between two aloes. It bears no potter's mark. Figure 6 shows a syrup jug with the inscription *s CERAS : NIGR*; it is decorated with a flower motif with a plant over it. It is marked with a symbol of three bells. Figure 7 is another syrup jug inscribed *s RUBI JDEI*. It is unmarked, and is decorated with two figures of naked women with banderoles; in the middle is a flower motif. Figure 8 illustrates a third syrup jug, one of a series of four; it is decorated with a console motif but has no inscription. It is marked *lpk*, i.e. *De Lampetkan*. Figure 9 shows a cylindrical pot inscribed *AXUNG: OXYGENAT*; it is decorated with a leaping stag and is marked with three bells.

The Museum possesses many apothecaries' mortars [2], one of which was cast by Segewyn Hatiseren and is dated 1531; another mortar by the same maker, dated 1540 and in much better condition, is in the Victoria and Albert Museum, London. A second mortar is that cast by Conradus Splinter in 1645 (figure 10); the only other known specimen by this maker is also in the Victoria and Albert Museum. Holland and Belgium are famous for the mortars cast there, principally at Deventer and Malines; they were made not only for pharmaceutical use but for household purposes, and were often given as wedding presents—hence such legends as *Amor vincit omnia* or its Dutch equivalent *Liefde verwint al dinc*. Mortars were also fashioned from materials other than metal—for example, marble, serpentine, wood, and glass. The Museum possesses specimens of all these varieties, as well as one of ivory.

Mention may also be made of the typically Dutch 'gaper,' which served as a signboard for a pharmacy. There are several of these in the Museum; one, with a monkey on the shoulder, is shown in figure 11.

In an upper room of the Museum are displayed medical instruments, books, and pharmaceutical objects not belonging directly to the laboratory. There are also portraits of famous physicians and apothecaries, such as Boerhaave and Vesalius, Seba and Abraham Francen. Seba is remembered for his cabinet of natural curiosities, which he sold to the Czar of Russia. In Amsterdam, then

the largest commercial city of continental Europe, it was not difficult to assemble strange and curious exotic objects; the sailors brought back such things from various parts of the world and apothecaries were always ready to experiment with new plants, drugs, poisons, and the like. Commerce affected apothecaries in another way also, for the East Indiamen and other ships had to be supplied with medicines for the voyage and for the colonies. Some of the medicine-chests made and fitted out for this purpose have survived, and three of those used on board merchant ships are now in the Museum.

Until the French domination of the Low Countries by Napoleon, the education of apothecaries took place in pharmaceutical practice only; candidates were examined by the guilds of apothecaries or the *Collegia Medica* and were not allowed to present themselves without a written certificate of practical experience. Some of these certificates, as well as diplomas granted to successful candidates, are preserved in the Museum. During their training, students used chests of simples containing specimens of all those drugs which they were expected to be able to identify at sight. The Museum possesses a beautiful example of such chests; it contains some hundreds of simples, many of which are no longer in use.

Those who wished to make themselves acquainted with living medicinal herbs had recourse to the *Hortus Medicus*, which issued free admission tokens to physicians, apothecaries, surgeons, and students. There are several of these tokens in the Museum, as well as guild medals awarded by the Guild of Apothecaries as a token of membership.

Lastly, we may recall that Fahrenheit worked in Amsterdam for the greater part of his life, making not only thermometers but hydrometers. At that time, the difficulty was to establish a fixed hydrometric scale for such instruments, and apothecaries were therefore advised in the Amsterdam pharmacopoeia to buy their hydrometers from one firm only. All the instruments made by this firm were signed, and one of them, made by Fahrenheit, is not the least of the treasures possessed by the Museum.

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Astronomers, physicists, and mathematicians, including some of the most celebrated among them, have been absorbedly interested in the measurement of time throughout the whole of history. For them it is often the essential independent variable, to be measured with the greatest possible exactitude. Professor Jaquerod here discusses recent developments in chronometry, a branch of science to which he has himself made notable contributions.

In order to measure time, it must be subdivided into equal portions of suitable size; for this, some periodic process must be discovered that has a constant period independent of internal or external factors, a fact which can be checked only by comparison with other periodic processes quite distinct from the one selected.

Over a period of centuries experiments were made with well known instruments: gnomons, clepsydras, sand-glasses, and the like. From the seventeenth century onward, more and more use came to be made of the gravity pendulum, proposed by Galileo and realized first by Huygens, and of the balance-wheel coupled to the spiral spring, also conceived and realized by Huygens. Hooke [1] made an important contribution to this phase of chronometry by discovering the law known by his name, which he enunciated in Latin as *Ut tensio, sic vis*; in modern terms, the elastic deformation is proportional to the force producing it. If this law were rigorously accurate, as was believed for a long time, the free oscillations of an elastic system would be isochronous; that is to say, their period would be independent of their amplitude.

The use of the pendulum and the spiral spring constituted an immense step forward. Up to that time, watches and clocks had been regulated—very roughly—by a verge, that is, a sort of balance-rod or ring executing a to-and-fro movement under the influence of some motive force (weight, spring) acting through an escapement (verge escapement). The period of the movement varied enormously, especially as the tension diminished, and a watch which did not vary by more than a quarter of an hour a day was a marvel. These variations arose mainly because the verge has no proper period, owing to the absence of any couple tending to bring it back to a position of stable equilibrium.

It is a curious fact that Galileo believed in the

strict isochronism of the pendulum; Huygens soon saw that this was illusory, and that the period increases with the amplitude. He sought to eliminate this failing by a device in which the pendulum was suspended from a flexible wire or ribbon, making contact on each side, as the pendulum oscillated, with metal cheeks of cycloidal shape. He showed mathematically that the oscillations of this pendulum should be isochronous. However, he had nothing but disappointment with it—for reasons which it would take too long to explain here—and abandoned the idea [1].

It was also appreciated fairly quickly that even the oscillations regulated by the balance-wheel and spiral-spring system are not isochronous when they are governed by means of an escapement. Precision of measurement has increased with technical progress, and as early as Huygens' day the effect of temperature on the spiral spring was noted; watches and clocks run slow when the temperature rises.

It can with truth be said that the greatest efforts of the last three hundred years were and still are directed to the elimination of these causes of error: deviations from isochronism and the effect of temperature. These efforts have been so successful that today the best astronomical clocks do not vary, on the average, by more than a hundredth of a second per day, and sometimes the variation may be only a few thousandths; there are watches which vary by only a few tenths of a second. Let us see how these remarkable results have been achieved.

(i) *The pendulum.* The numerous attempts to make the pendulum isochronous have all been fruitless, and even today the only method of ensuring constancy of period is to keep the amplitude constant—a makeshift solution. The necessity of controlling the oscillations, by means of an escapement, exerts a considerable effect on the isochronism, and the aim has been to reduce this

effect to a minimum. Shortt's clock with a so-called 'free' pendulum gives a remarkable performance in this respect.

On the other hand, compensation, i.e. elimination of the effect of temperature, has been achieved with a high degree of accuracy. Graham (1715) was the first to construct a compensated pendulum—the mercury pendulum. Here the rod is of steel, carrying a mercury container whose thermal expansion raises the centre of oscillation and thus compensates for the expansion of the rod, which tends to lower it. Later (1726), John Harrison conceived the familiar grid pendulum, but the most important advance was made much more recently by C. E. Guillaume [2], who investigated the anomalies in the coefficients of expansion of nickel steels. These coefficients, when plotted against nickel content, give a curve with a very sharp minimum at 36 per cent Ni, where the coefficient of thermal expansion is almost zero. The alloy of this composition is called Invar, and is widely used in metrology. A pendulum with an Invar rod has an almost constant length; the very small residual expansion can be compensated by the expansion of the bob.

Unfortunately, nickel steels are unstable: their dimensions change slowly with time, causing a variation in the rate of the clock-mechanism. This can be eliminated by a suitable thermal treatment, and, as Guillaume showed, by the inclusion of chromium in the alloy. Nowadays the majority of precision clocks have pendulum rods of Invar.

The effects on the period exerted by the ambient air have also been much studied, e.g. by Stokes and Bessel. There are several such effects, one of which is a damping, causing a slight change in the period. But the most important effect is the action of the air in virtue of Archimedes' principle: it produces an upthrust, whence an apparent diminution in the weight, that is, in the restoring force. Finally, air which is carried with the bob increases its apparent mass. Variations of barometric pressure and temperature make themselves felt, by varying the density of the air. Methods of compensating for them have been sought, for instance by combining a mercury barometer with the pendulum. This procedure has been abandoned, and the modern method of eliminating the influence of pressure-variations is to place the clock in an enclosure in which the pressure and the temperature remain constant. All astronomical clocks are so enclosed.

(ii) *Balance-wheel and spiral-spring (watches).* Ever since the invention of the balance-wheel and spiral-

spring system, the makers of chronometers, and many scientists, have paid much attention to improving the compensation and the isochronism of time-keeping mechanisms, for the defects, particularly as regards compensation, soon became obvious. These studies were stimulated by a prize of £20 000 offered in 1714 by the British Government to anyone who should solve the problem of the determination of longitude at sea—that is, of constructing a chronometer which would give reliable service under sea-going conditions. After a long delay, the prize was awarded to Harrison in 1773 for his marine clock, in which the bi-metallic balance-wheel, which compensated for the effect of temperature on the spiral, played an essential part.

Early in the present century, Guillaume [3] produced an entirely different solution. Instead of compensating for the effect of temperature by exerting an opposed effect on the balance-wheel, he eliminated it in the following manner. A Swiss maker of chronometers observed an unexpected temperature-effect in a watch having an Invar spring. Guillaume made a systematic study of the phenomenon, and discovered that the plot of Young's modulus against temperature for an alloy containing approximately 42 per cent of Ni passes through a maximum and minimum, instead of following a uniform, linear course like that for steel. At these points the thermoelastic coefficient is zero. He then found that addition of 12 per cent of chromium yielded an alloy which, in the region of normal operating temperatures, had a modulus that does not vary with temperature. This alloy is called Elinvar. A spring made of this alloy is said, not altogether correctly, to be auto-compensated. At the present day there are many such alloys—Metélinvar, Nivarox, Isoval, etc.—and the use of a steel spring and bi-metallic balance mechanism has been practically abandoned, except for marine chronometers and watches of the highest precision.

A theoretical attack on the problem of isochronism was begun during the last century. Phillips [4] made an essential contribution: he showed that the geometry of the spiral must conform to rigorous laws, and particularly so the form of the terminal curves. Phillips' theory has been simplified and developed further during the present century by Keelhoff and, above all, by Haag [5].

All these mathematical theories assume a material obeying Hooke's law. The present writer has studied this point experimentally, using both torsional and flexural tests, and has shown that

isochronism is never, or hardly ever, realized, even in a free system at very low amplitudes, the limiting case in which it is assumed to occur. What is more, variations in period are generally the more rapid the smaller the amplitude. Mechanisms constructed from the majority of metals and alloys exhibit these deviations from isochronism, sometimes considerable and often varying with amplitude in a curious manner. This behaviour can be modified in various ways by thermal and mechanical treatments. Among metallic substances, certain alloys of copper, such as cupro-beryllium, yield mechanisms whose isochronism is remarkable at very low amplitudes. On the other hand, glasses have excellent isochronism, with deviations $1/30$ – $1/100$ th of those for steel. Efforts should be made to use them in precise chronometry, for they would offer many advantages [6].

In any case, chronometry has now reached a turning-point and, although the pendulum and the balance-wheel and spiral-spring can look forward to continued application for everyday measurement of time, they are both almost certain to be ousted for high-accuracy measurements by the tuning-fork clock, and especially by the quartz-crystal clock and that described as molecular or atomic. The general principle is the same in each case, namely to use an oscillatory motion for subdividing time into equal fractions, and the difficulties to be overcome are essentially the same as in classical chronometry.

A tuning-fork executes practically isochronous vibrations. These can be maintained by a circuit (figure 1) containing a triode and two small polarized electromagnets. The sinusoidal current from this circuit is fed to a synchronous motor and clockwork mechanism. Attempts are made to keep the amplitude constant and, to prevent variations of frequency arising from variations of temperature, the fork is made of Elinvar. The error is of the order of 10^{-4} per cent, or $1/10$ th of a second per day. It is difficult to reduce it further.

The quartz clock [7] utilizes the elastic vibrations of a quartz rod, ring ('doughnut'), or plate maintained by an oscillating electrical circuit, thanks to the piezoelectrical properties of quartz.

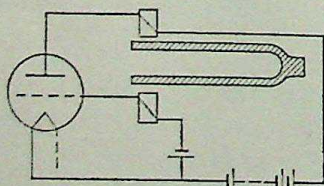


FIGURE 1

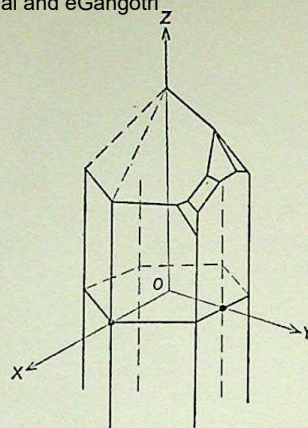


FIGURE 2

Piezoelectricity was discovered in 1880 by Pierre and Jacques Curie [8]; its essentials, as far as they interest us here, are as follows.

Figure 2 is a sketch of a quartz crystal with three rectangular reference axes. OZ is the crystallographic or optical axis, OX the electrical axis. Let us describe within the crystal a regular parallelepiped. If a pair of specially well developed faces is perpendicular to the OX axis, the parallelepiped is said to be produced by an X-cut, and so on. Oblique cuts are also of interest, as we shall see.

Let us consider such a parallelepiped parallel to the three axes. A pressure exerted along OX or OY produces two electrical charges of opposite sign on the faces perpendicular to OX, proportional to the pressure. A tensile force along OY produces opposite charges. This is the direct piezoelectrical effect. The inverse effect, predicted by Lippmann in 1881, is the production of an expansion or contraction along OX or OY, but not along OZ, by an electrical field acting along (or against) the direction of OX. If the quartz crystal is placed in an oscillating field, e.g. a sinusoidal one parallel to OX, it will be set in forced vibrations, which will attain maximum amplitude at resonance, i.e. when the frequency of the oscillating field is exactly equal to the natural frequency of elastic vibrations (number of oscillations per second) of the crystal. This crystal then imposes its natural frequency on the circuit.

Figure 3 shows the simplest arrangements (Pierce, and Pierce-Miller, oscillators) for maintaining these oscillations in a way suitable for controlling a chronometer. The frequency of vibration, which depends on the size of the crystal, is of the order of 100 000 cycles per second—much too large to be used directly. An electronic

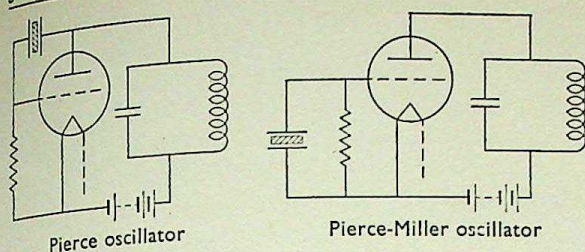


FIGURE 3

device 'demultiplies' this frequency, that is, lowers it successively to $1/2$, $1/5$, or $1/10$ th of its value, and finally to a frequency of say 1000 or 100, suitable for operating a synchronous motor which rotates with the same regularity as the vibrations of the controlling quartz, and can move the hands of an appropriate clockwork mechanism.

This regularity depends on two factors: isochronism of the quartz vibrations, and variations in temperature. Since the quartz crystal is part of a condenser which is itself part of an oscillatory electrical circuit on which it imposes its natural frequency, the amplitude of the vibrations will be a function of the power-input. If this power is plotted along abscissae against frequency as ordinates, a curve similar to that for cupro-beryllium is obtained. Since there are difficulties in driving the crystal at the very low power at which oscillations are strictly isochronous, there is a certain deviation from isochronism; this is countered—as for a clock with a gravity pendulum—by striving to maintain the power-input at a constant value.

To deal with effects due to temperature-variations is a complex problem. If the crystal has the form of a plate and executes longitudinal vibrations along OY, a strongly negative thermoelastic coefficient is encountered. This coefficient can be made positive by changing the direction of the cut, and the vibrations then follow a complicated pattern. An orientation of the cut is sought such

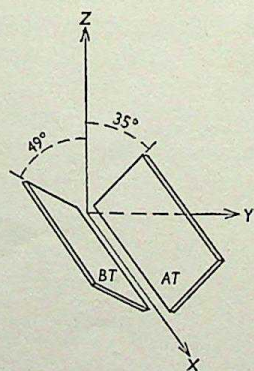


FIGURE 4

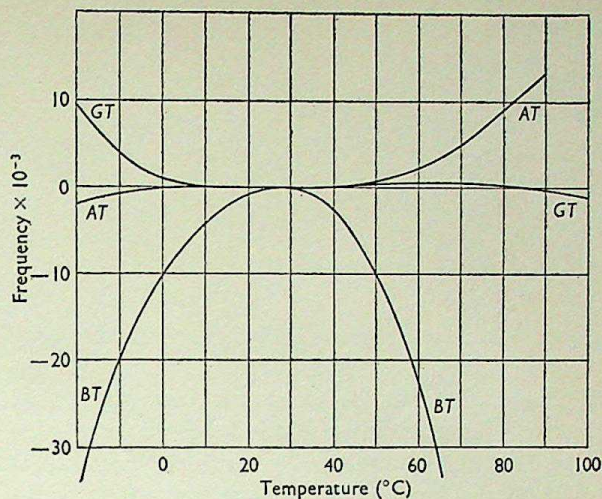


FIGURE 5

that the frequency/temperature curve exhibits either a maximum ($dn/dT = 0$) or a point of inflexion to which a horizontal tangent can be drawn. Figure 4 shows two cuts which are used, and figure 5 their frequency/temperature characteristics. The GT cut, much used for high-precision quartz clocks, is not shown in figure 4; however, figure 5 shows that, for this cut, the effect of temperature on frequency is practically zero between 0 and 100°C [9]. The quartz ring or 'doughnut' is excellent but requires careful handling, especially when mounting it. In any case, the temperature of the crystal must always be maintained constant to within a few thousandths of a degree by thermostatic control: this is no simple matter.

How accurate are the best quartz clocks? For comparison, it may be recalled that good astronomical pendulum clocks, particularly those with Shortt pendulums, keep time to within a few thousandths of a second per day, a deviation of $2-3 \times 10^{-8}$. The error of the best quartz clocks is not greater than 10^{-9} , or $1/10$ 000th second per day, i.e. the deviation of such a clock is less than $1/10$ th of that of a good astronomical clock. It is obvious that comparison can no longer be made against sidereal time determined from the rotation of the Earth. For one thing, there is an uncertainty in the astronomical determination of this time of $0.01-0.02$ sec, and for another, as will be seen below, the sidereal day is not an absolutely constant quantity, but suffers from variations that cannot be tolerated in chronometry. The accuracy of time-keeping by various clocks can be determined only by intercomparisons. The main observatories keep several of them (eighteen at

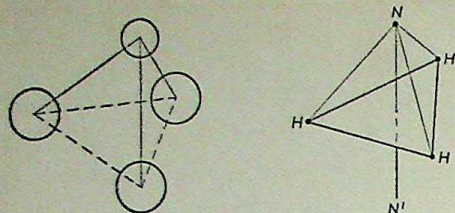


FIGURE 6

Greenwich, for instance, piloted by quartz rings).

Does the quartz clock suffer from any disadvantages which offset the enormous advantage of its high precision? It would, indeed, be surprising if it did not. The main trouble is the drift in frequency which is observed in the first years of running, generally a very slow acceleration tending asymptotically towards constancy. This ageing is suffered by a quartz crystal even in very high vacuum, and arises from various causes still little understood: evaporation of the electrodes deposited on the crystal by sublimation, adsorption of gases, changes in the structure of the quartz itself.

In addition, the electronic equipment of these clocks is subject to irritating breakdowns due to the multiplicity of valves, condensers, and so on. When the system is started up again after any stoppage, it only slowly settles down to operation at its initial rate. Is it possible to eliminate all these inconveniences? Great hopes are placed in the molecular or atomic clock. This is a time-keeper controlled by a truly constant oscillation, completely independent of external conditions. It can be assumed that the internal vibrations of any molecule, or atom, fulfil this condition absolutely. The ammonia molecule, NH_3 , for example, has the structure shown in figure 6—a pyramid on an equilateral triangular base, with the nitrogen atom at the summit. This atom can vibrate between the two positions N and N', emitting an electro-magnetic radiation of frequency 23 870 Mc/s, with a wavelength of 1.2658 cm, very far in the infra-red. The molecule can be set in vibration by radiation of the same wavelength, which is consequently absorbed. The resonance curve has a sharp maximum. A long (10 m) tube, serving as a guide for a wave of suitable frequency, and filled with gaseous ammonia, will transmit radiation without or with attenuation according as the frequency of this radiation is exactly equal to, or slightly less than, 23 870 Mc/s.

At the moment of resonance there will be a definite signal from this tube, which can be adapted for regulating a timepiece, such as an ordinary

quartz clock. This is the principle of the molecular clock, constructed by H. Lyons at the National Bureau of Standards, Washington [10]. Unfortunately, it has hitherto functioned only intermittently, the main difficulty having arisen from variations in the very low pressure of ammonia in the tube due to various causes, notably adsorption. However, there are reasons to suppose that it will be possible to surmount this difficulty, particularly by using an isotope of a heavy element—caesium, for example—and that timepieces may be constructed with a much higher precision than that previously achieved by other methods.

To conclude, let us see of what value the Earth is as a clock. Up to the present—though it will not be so in the future—the mean solar day has been taken as the unit of time. This depends essentially on the angular velocity of rotation of the Earth, making allowance for its translation round the Sun. Exact information about the determination of the length of the hour will be found in an article by Sir Harold Spencer Jones [11], at the end of which he says 'A new era of time-measurement has arrived, and clocks made by man now hold out a distinct promise of being able to convict the Earth of irregularities in time-keeping.'

Some considerable time ago, indeed, scientists first supposed, then proved and calculated, that the tidal friction between oceans and crust is gradually diminishing the angular velocity of the Earth. The effect is extremely small—one or two thousandths of a second per day in a century—and there is no immediate hope of directly demonstrating it experimentally. Experiment has, however, revealed something else, which was not predicted (though it was envisaged by Newton) and which astronomers and geophysicists are now studying with great interest, namely variations in the angular velocity, ω , of the Earth around its mean value, which is practically constant. Apart from the effect of tides, the angular momentum of the Earth, $I\omega$ (I = terrestrial moment of inertia), is constant. If for any reason I should vary, ω would vary correspondingly. I depends on the total mass of the Earth and its distribution around its axis of rotation. Thus any transposition of mass in the Earth will produce in general a change of angular velocity. When a man travels towards the equator, he lengthens the day; when he travels away from it, he shortens it. Of course the effect is insignificant, but if considerable masses are displaced (e.g. of air, or of water to the equator

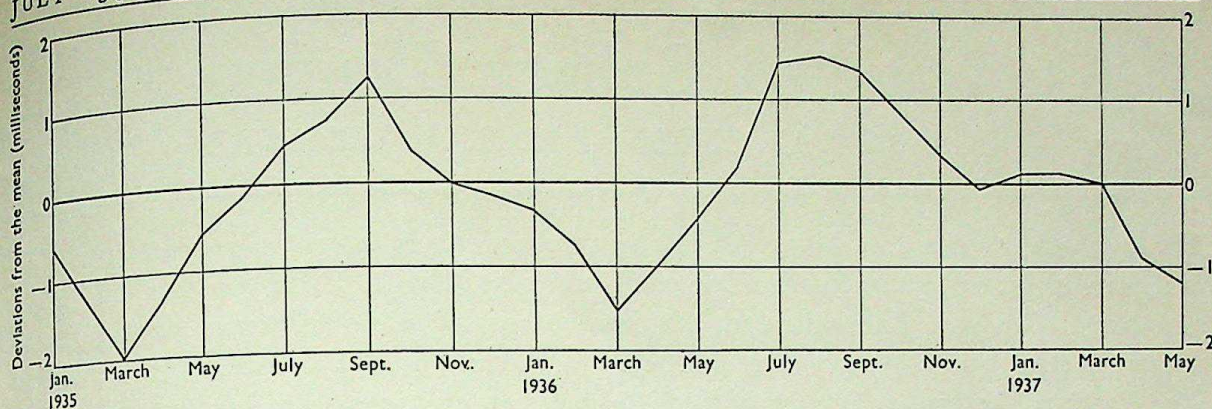


FIGURE 7

through melting of the polar ice-cap, by outpourings of molten lava, by the raising up of continents, etc.), the variations in the length of the day might become appreciable. If this were to happen, a disagreement between sidereal and clock time would occur: clocks would appear to gain or lose.

Astronomers have for some long time observed irregularities in the movement of the Moon (which also serves as a clock) for which there has been no theoretical explanation. Similar and parallel irregularities have been observed in the motions of the planets. There can be only one explanation: the Earth is at fault.

In 1937 Stoyko [12] published records of the running of a series of astronomical clocks at the Paris, Washington, and Charlottenburg observatories, which vary in parallel with one another. Figure 7 shows the results for the period 1st January 1935 to 30th April 1937: the mean monthly deviations, in thousandths of a second per day, are plotted along the ordinates, and the times of observation along the abscissae. A thou-

sandth of a second per day may be small, but in a month it adds up to three hundredths—quite a perceptible amount. The graph shows that there is an annual periodicity among the variations.

These variations of angular velocity are very apparent with quartz clocks, whose accuracy (as already stated) is at least ten times as great as that of ordinary astronomical clocks; and there will soon be some hundreds of these quartz clocks distributed over the two hemispheres. It is already known that there is an annual periodicity in the terrestrial fluctuations, as well as a semi-annual one, and that there are also fortuitous changes which sometimes occur quite suddenly. Close study of these arresting facts, which will need international collaboration, and the efforts made to define their causes, will certainly lead to a more exact knowledge of several interesting phenomena in geology and geophysics. One is even justified in hoping for important discoveries, perhaps sensational ones, which will compensate us for having to give up the Earth as a time standard.

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Some scientific investigations at the National Gallery, London

F. I. G. RAWLINS and A. E. A. WERNER

The methods described in this article are the result of closely co-operative teamwork. The authors wish to emphasize the leading parts taken by Miss R. J. Plesters, Mr J. S. Mills, and Mr I. Graham. In particular, the development of microtechniques has progressed under the stimulus of the Conservation Department, and has now become routine practice. The Nuffield Foundation has made possible the long-term researches in chemical physics.

Previous communications to ENDEAVOUR [1, 2] have described the general principles underlying the application of scientific methods to the problems of conservation. It is now proposed to discuss in some detail processes that have been developed during the last few years. These cover some of the routine work in which the laboratory supports the restorers' studio, but in addition there is now the programme brought into being as a result of the Nuffield Foundation's generous grant for long-term research.

We are not concerned with the compilation of records; what is involved at this stage is a conspectus of tasks undertaken to learn about the special way in which the various components of a painting are physically related to one another. Alongside has gone the first attempt to apply chromatographic methods to the elucidation of the chemistry of the natural resins, and to their detection in paint media. In addition, a study is being made of the mechanism involved in the diffusion of solvents through linocyn films.

It will be observed that the approach in all these cases is towards a physico-chemical study of the behaviour of the substances from which 'classical' paintings are normally constructed.

MICRO-SECTIONS OF PAINT SAMPLES

Although painting-techniques may have differed through the ages—modern methods being usually simpler—there is, broadly speaking, one basic principle underlying them all, namely that a painting is a stratified object. This layer-like structure is essentially fourfold, and (starting from the back) it comprises (i) the support, (ii) the ground (or gesso), (iii) the paint layers proper, and (iv) the protective coating (or varnish).

Since a knowledge of the stratified structure of a painting is frequently of interest to the restorer,

and also can provide valuable information about the methods used by the old masters in building up their paintings, a method for mounting minute fragments of paint for a microscopical study of the layers in cross-section has been developed. The technique is similar to that employed in the preparation of cross-sections of metals or minerals. The paint-fragment is embedded in a suitable mounting medium, ground with emery papers of increasing degrees of fineness, and given a final polish on a buffing wheel. The primary question is the choice of a suitable mounting medium. In the past, attempts were first made with mixtures of paraffin wax and ceresine, but they were not very successful. The mounting medium was too soft, and during the grinding (or cutting) there was a danger of fracturing the paint-fragment. A method using polymethyl-methacrylate resin (Perspex) as the mounting medium was introduced to overcome this difficulty.

However, the material that offers the best possibilities as an embedding medium is the polyester resin marketed under the trade name Marco Resin 26 C, which has already found considerable use in museum work for the embedding of comparatively large specimens [3]. Polyester resins with similar properties are also marketed for this purpose as Ceemar Resin and Beetle Resin 4116. The advantages displayed by these polyester resins as embedding media are briefly as follows: (i) they are cold-setting, thus eliminating even a theoretical risk of damaging the paint-fragment by heat; (ii) the prepolymer is a mobile liquid which easily penetrates the paint-fragment, and also permits air-bubbles to be dispersed without difficulty; (iii) they are water-white and have a refractive index (c 1.5) approximating to that of Canada balsam; and (iv) when set they are almost unaffected by acids, alkalis, and organic

solvents, except upon prolonged exposure. Furthermore, since it is not necessary to apply pressure during setting, the mounting can be carried out in a flexible polythene mould, from which the solid block of resin can easily be ejected by pressing the sides. 'Flexicubes,' sold for making ice-cubes in refrigerators, have been found most convenient for this purpose.

The optical examination of the cross-section reveals the arrangement of the layers, and their appearance often gives a clue to the type of pigment present. This is normally confirmed by a chemical analysis of an unmounted paint-fragment from the same area of the picture, using the modern organic reagents for metals in conjunction with Feigl's spot-test technique. However, in favourable circumstances it is possible to carry out microchemical tests on the actual cross-section. Thus the presence of white lead in a paint-layer can be readily shown by the formation of a bright yellow colour when the cross-section is treated with a drop of dilute hydrochloric acid followed by a drop of potassium iodide solution. Similarly the presence of iron pigments can be revealed by the Prussian blue test. The chemical reagents do not penetrate the paint-fragment; if it is sufficiently thick, it can be reground so as to expose a fresh surface, upon which further chemical reactions may be carried out. This development is proving of great value for the identification of pigments present in individual layers of paint, since in the majority of cases it is not possible to obtain samples of the separate paint-layers for examination.

As the dates of the discovery of very many pigments are known with some accuracy, this knowledge can be used in certain circumstances to determine the earliest date at which a picture could have been painted, and thus perhaps to expose faulty or fraudulent ascriptions. Two such instances occurred recently during a review of paintings in the National Gallery. Specimens of blue and green *original* paint (in taking specimens for analysis, care must naturally be exercised that the area from which the specimen is taken is original paint and not an area of later repaint) from a picture ascribed to the seventeenth-century Dutch school were found to contain Prussian blue and opaque chromium oxide respectively. Prussian blue was first used in Holland in the second half of the eighteenth century, and chromium oxide was not in common use as an artists' pigment until about the middle of the nineteenth century. The second example concerned a painting ascribed to Murillo: a specimen of original blue paint was found to contain cobalt

blue, a pigment first discovered in 1804 by the French chemist Thenard.

Figures 1-6 are photomicrographs of cross-sections serving to illustrate the varied appearance to be observed in the build-up of paintings of different periods by different artists. In figure 1 the layers 1-4 represent the original painting, which dates from 1530 to 1535; the ground is chalk, and the red layer consists of an iron oxide pigment upon which paint layers containing blue azurite and green malachite are superimposed. The subsequent layers consist of dark overpaints in oil and varnish which were applied about 1740. The sharp division between the original and the overpaint is clearly marked: incidentally, the painting has been now restored to its original condition by the removal of the eighteenth-century overpaint. Figure 2 is typical of the technique of early Flemish paintings, comprising compact, relatively thin and regular paint layers. Figure 3 is of interest because it shows how original paint-losses have been covered by repainting. The light blue layer 4 consists of azurite in a pure oil medium; it represents the original Holbein paint. At some time, fragments of this flaked off, uncovering the white underpaint (layer 3), and the resulting lacunae were overpainted. Thus layer 5 (which is rather greener than it appears in the reproduction) consists of a mixture of azurite and white lead in an oleoresinous medium. This would turn a dirty olive-green as the medium yellowed, and probably explains why a repaint containing Prussian blue (layer 6) was applied at a later date. Figure 4 is characteristic of the technique employed by Rembrandt in his later period, being similar in its general features to other late paintings by this artist. The paint, rich in oil, is laid on in relatively thick layers. The ground shown in figure 5 has the coarse crystalline structure typical of that used by many Venetian painters.

CHROMATOGRAPHY OF NATURAL RESINS

The chemical examination of paint-media and varnishes, especially as regards the detection of natural resins, presents a more difficult problem than the identification of pigments, for which precise sensitive tests are available. This is due to the chemical complexity of the materials involved.

The natural resins, properly so called, are hydrophobic substances of terpene-like character, and are to be distinguished from the gums, which consist largely of water-soluble polysaccharides. However, there are also intermediate substances, such as asafoetida, myrrh, and frankincense, which

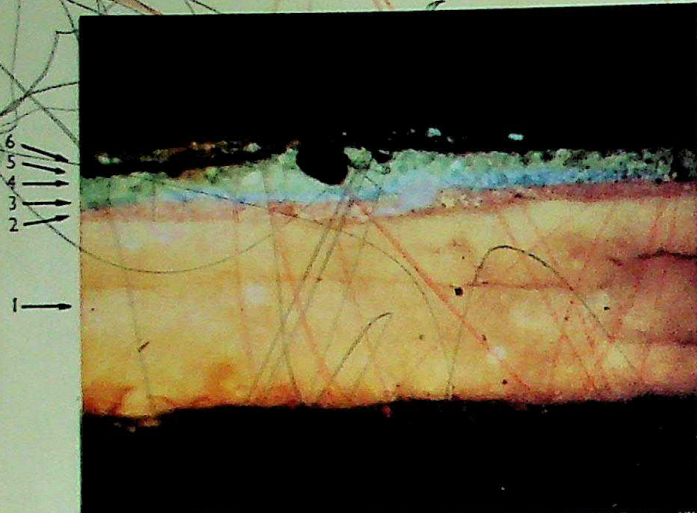


FIGURE 1 - Fragment of discoloured green paint from a panel-painting in Chichester cathedral. Layers 1-4 represent the original paint. Above them are layers of later overpaints in oil and varnish. ($\times 95$)

FIGURE 2 - Paint-fragment from picture on the back of a panel-painting by Gerard David (1450 or 1460? - 1523). Layer 5 is a dirty gray paint covering the picture. The reddish paint in layers 2-4 consists of iron oxide pigments of different shades mixed with white lead. ($\times 95$)

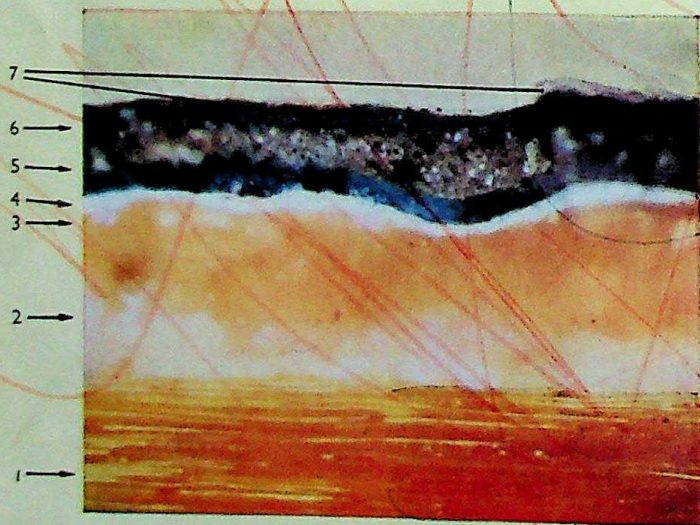


FIGURE 3 - Fragment of blue paint taken from the background of a Holbein (1497?-1543) painting. This cross-section shows the complete system of layers from the wood of the support (layer 1) to the varnish (layer 7). ($\times 95$)

FIGURE 4 - Paint-fragment from the area of a shadow on a hand from a late Rembrandt (1606-69) portrait. Note the use of a dark ground (layer 1) used to prime the canvas support; also the coarsely-ground white lead in layer 4. ($\times 95$)



FIGURE 5 - Fragment of ground from painting by Giovanni Bellini (1430?-1516). The thick ground has been built up in a series of separate layers. The dark brown colour is due to the presence of an unusually high proportion of glue. ($\times 95$)

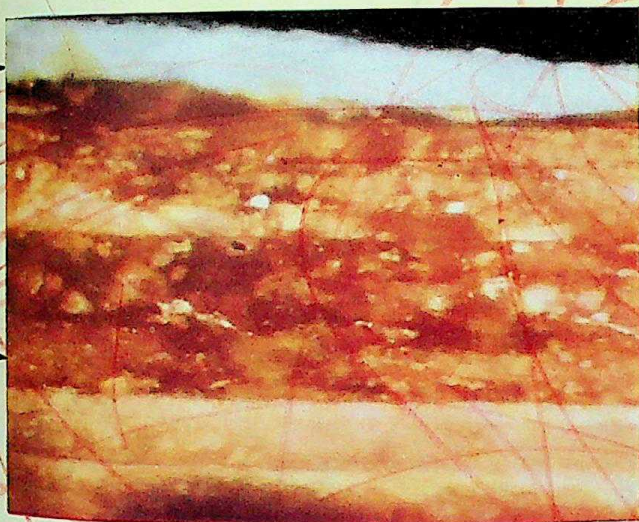


FIGURE 6 - Fragment of brownish-green paint representing foliage, from a painting by Pollaiuolo (1429-98). Note in layer 4 the large transparent dark green crystalline particles of verdigris, which are embedded in a matrix of white lead coloured with copper resinates. On the surface the latter has turned brown. ($\times 95$)



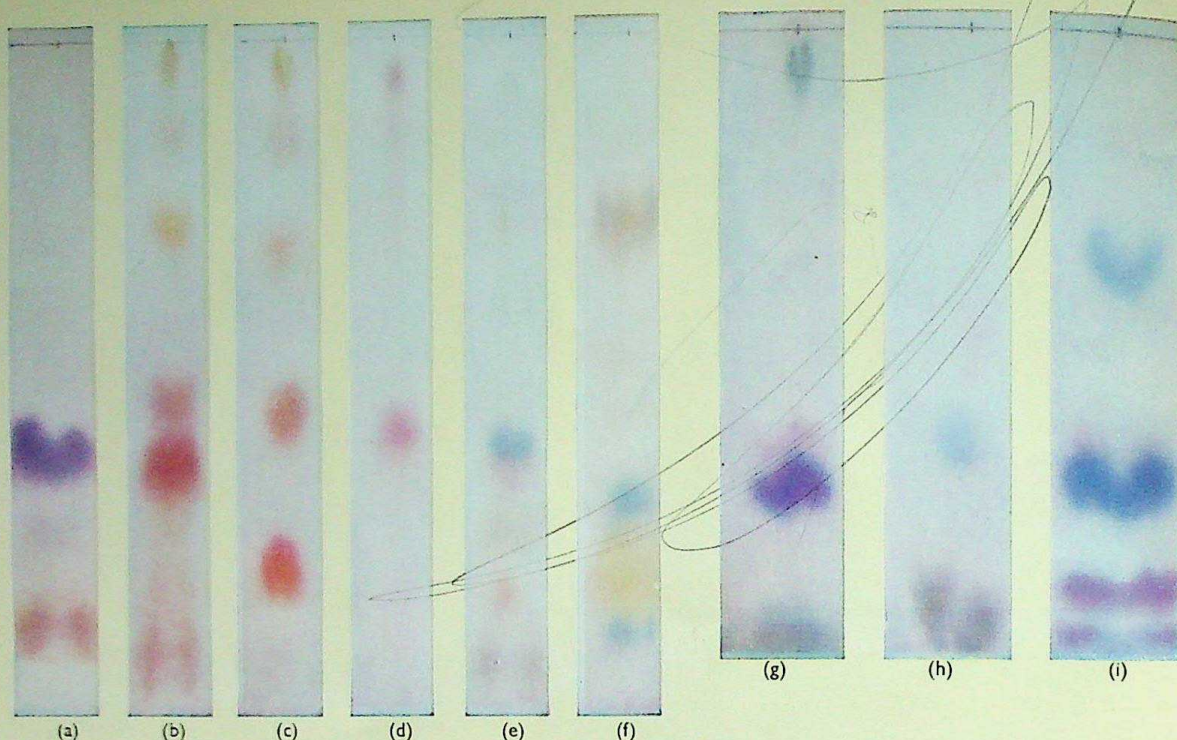


FIGURE 7 - Reverse-phase partition chromatograms, on filter-paper, of some natural resins. 0.1 mg of the resin in a volatile solvent is placed at the top of the strip of filter-paper impregnated with the stationary phase (odourless kerosene). The mobile phase used for elution consists of iso-propanol (65 parts) and water (35 parts).

- (a) Rosin. This consists largely of abietic acid, which is responsible for the main blue spot.
- (b) Mastic. From *Pistacia lentiscus*.
- (c) Dammar. From various species of *Hopea*. The five spots visible are (reading downwards): β -resene, tri-terpene monoketones, monohydric alcohols, keto-alcohols, and a mixture of diols and a keto acid.
- (d) Congo copal. Fossil resin said to originate from *Copaifera demeusei*. Only the chloroform-soluble portion of the resin has been used in preparing this chromatogram.
- (e) Copaiba. Balsam from *Copaifera langsdorfii* and similar species.
- (f) Manila elemi. From *Canarium luzonicum*. The zone at the top is due to a mixture of α - and β -amyrin.
- (g) Canada balsam. From *Abies balsamea*. The main blue spot is probably due to abietic acid. (Strasbourg turpentine from *Abies pectinata* gives an identical chromatogram.)
- (h) Sandarac. From *Tetraclinis articulata*.
- (i) Venice turpentine. From *Larix decidua*. Once again the main blue spot is probably due to abietic acid.

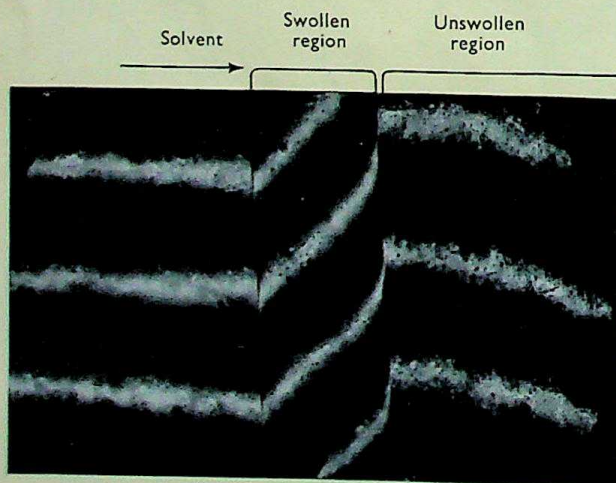


FIGURE 8 - Swelling of oil varnish in xylene.



FIGURE 9 - Swelling of oil varnish by acetone.

consist of a mixture of materials belonging to both these classes; they are known as oleo-gum-resins. The natural resins themselves are rather arbitrarily subdivided into the solid, typical varnish resins, which include dammar, mastic, copals, and rosin, and the oleo-resins or balsams, such as the turpentine, copaiba, and elemi. The latter contain a higher proportion of essential oil and are syrupy or semi-solid at ordinary temperatures. The difference between resins and balsams is one of degree only; evaporation of the excess of essential oil in a balsam will leave a solid resin. Thus the oleoresin turpentine from Coniferae yields rosin when the essential oil is distilled off.

Although natural resins have been the subject of extensive chemical investigation for about 150 years, the early results achieved, which are very fully reviewed by Tschirch and Stock [4], leave one with a picture of intimidating complexity and some doubt as to the homogeneity of many of the compounds described. This is due largely to the fact that the methods then available for the isolation and purification of the majority of the resin components were not adequate. The early work was devoted largely to the acidic constituents and, despite the fact that the two crystalline triterpene alcohols α - and β -amyrin were isolated from elemi over fifty years ago [5], comparatively little work has been done on the analysis of the neutral fractions of natural resins. There has been a tendency to group them together under the vague names of α - and β -resenes. Our present work on the chemistry of dammar and mastic suggests that, for these resins and no doubt for others also, the distinction between the alcohol-soluble α -resene and the alcohol-insoluble β -resene has a sound basis. It has, however, been found that the α -resene fraction is a complex mixture of triterpene alcohols, ketones, ketols, and the like, whereas the β -resene fraction consists of a mixture of polymeric materials of low oxygen-content having a wide range of molecular weights.

The primary stimulus to apply reversed-phase paper chromatography to the examination of the constituents of natural resins lay in the need for devising a trustworthy method of identifying these resins when present in paint-media. It was found that fresh natural resins could in fact be readily distinguished chromatographically using a reversed-phase system specially elaborated for this purpose [6]. However, the original problem still remained largely unsolved, since it was found that, even after a few years, natural resins in thin films are completely oxidized and no longer give dis-

tinguishable chromatograms using this system. Instead, these show a single spot of high R_f value, corresponding to the polar oxidation products. At the very least, such a spot points to the presence of a natural resin in a paint medium. The problem has therefore now assumed a different form, namely the development of a suitable method of analysing these oxidation products.

As in other fields, paper chromatography will probably be of most use as a convenient method of following the course of the isolation of di- and triterpene constituents from resins and other natural sources. Moreover the technique provides a certain amount of information about the nature of the constituents themselves, since their positions in the chromatogram are dependent primarily upon the number and nature of the functional groups present. In a reversed-phase system such as this, the more polar the constituent the farther it travels from the origin.

In figure 7 are reproduced paper chromatograms of selected resins. In them, the positions of the resin constituents have been located using the Halphen-Hicks reaction [7]; the chromatogram is sprayed with a solution of phenol in carbon tetrachloride and then suspended in bromine vapour for a short time.

DIFFUSION PHENOMENA IN FILMS

One of the recurrent problems of conservation concerns the action of solvents on varnish and paint. Before any picture can be cleaned, the twin questions of what solvents to apply, and in what strength, must be decided, and in the absence of any basic knowledge these decisions can be made only in the light of custom, experience, and trial-and-error. The nature of the problem is complex, the factors are many, and the complete answer is still a long way off. Of the many aspects that must some day be examined, three have been chosen for preliminary work: the process of diffusion of solvents into varnish, the solvent power of mixed liquids, and the mechanical properties of swollen varnishes.

There is a particular interest in the mechanism of swelling, because whereas the spirit-varnishes composed wholly of soluble resins are easily removed, the really troublesome cases are always those in which the resin has been mixed with a drying oil. Such a varnish may be almost entirely insoluble in organic liquids, and will merely swell and become to a certain extent softer, thus allowing of its removal by gentle mechanical action.

The diffusion of solvents through cellulose

acetate and other polymers has been studied by Robinson [8], and although the polymers he used have few similarities to oil varnishes, his technique of interference microscopy is appropriate. A film of varnish is clamped between half-rhodiumized glass plates arranged at a small wedge-angle, and is examined by monochromatic light collimated to a parallel, normally incident beam. As the solvent—or, more accurately, penetrant liquid—advances into the material from the edges, the change in refractive index causes a distortion of the Fizeau fringes, from which the gradient of concentration can be calculated. The boundary between swollen and unswollen material has in every case appeared sharp: the typical sudden change in refractive index visible in figure 8 points to a process of solvation of the linoxyn structure, while the ensuing gradual change in refractive index through the swollen material is due to true diffusion. Figure 9 shows a late stage in a diffusion experiment. The varnish is fully swollen near the edge, the small slope of the fringes showing that the gradient of concentration is low there, and only a narrow island of unswollen material remains. A complete analysis of the fringe pattern is made difficult by the leaching-out of soluble resins and unpolymerized oil. Still, the technique is capable of yielding a qualitative description of events in simulated cleaning operations: for example, one can see how far the varnish is penetrated when flooded with a penetrant liquid for a limited time, then with a non-penetrant, miscible with the first and tending to withdraw it from the varnish.

Mixtures of organic liquids are invariably employed by restorers, who have come to recognize, broadly speaking, two classes of liquid: penetrant liquids or solvents, and non-penetrant liquids or restrainers, typified by ethyl alcohol and white spirit respectively. Our experiments show that, in fact, mixtures of these may have a swelling-power much greater than either used alone; thus a 60 : 40 mixture of turpentine and ethyl alcohol will eventually swell a linoxyn film to three times the extent caused by alcohol alone. This large equilibrium-swelling is, however, only slowly reached, and in

practice turpentine can be regarded as a restrainer for ethyl alcohol, slowing down its initial action.

In its mechanical properties linoxyn has been found to have certain resemblances to rubber, becoming as it were slowly more vulcanized with age and exposure to light. From the point of view of conservation it is important to find out the influence of age, humidity, and swelling by solvents on these mechanical properties, but the measurement of any single elastic constant is not a simple matter. Recent advances in rubber technology should help in suggesting experimental methods and in interpreting the results.

An example of this work may be quoted. The brittleness of samples of varnish, varying inevitably in thickness, is measured, not with reference to the smallest mandrel over which they may be bent without cracking, but as the highest temperature at which a sample ruptures during a 20 per cent extension at a standard rate. In this way one can measure the increase in brittleness due to the removal of unpolymerized oil by solvents, or the decrease that can be brought about by the introduction of plasticizers. Such plasticizers can be added to dried-up and brittle films if applied in admixture with a liquid of good swelling-power. The function of the latter is to expand the cross-linked linoxyn structure, which acts as a molecular sieve, and so to permit the entrance of bulkier molecules; afterwards the volatile liquid is allowed to diffuse out and evaporate, leaving the plasticizer locked within. A rather brittle specimen of oil varnish was left in dinonyl adipate for five months, during which time a small quantity was absorbed—enough to change by 5°C the temperature at which fracture occurred in the test for brittleness. The same change could be induced in 18 hours by soaking the specimen of varnish in a 4 : 1 mixture of dinonyl adipate and benzene; in this case the brittleness was not measured until a month had passed, to ensure the complete removal of benzene. These and other experiments on the swelling of varnishes are more fully described in a paper read at the conference of the Oil and Colour Chemists' Association last year [9].

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Biochemical light upon an ancient poison: a lethal synthesis

SIR RUDOLPH PETERS

A decade ago, the toxic principle of the South African plant *Dichapetalum cymosum* was shown to be fluoroacetic acid. Subsequent study of this substance has led to biochemical discoveries of great interest. The action of fluoroacetate, itself innocuous, proves to be due to its conversion by enzymes into a toxic substance; this is precisely the opposite of the detoxication mechanism by which the body commonly attempts to eliminate poisonous substances.

For a long time it was thought that once a chemical substance entered the protoplasm of the cell it ceased to behave as such, but this view is now entirely obsolete. Differences may indeed appear in the behaviour *in vivo* as distinct from that *in vitro*, but the explanation for these is sought in the organization of the tissue. Thus the advances made in the last twenty years in our knowledge of the details of the disposal in the higher animals of pyruvic acid have taught us the dependence of this stage in metabolism upon some members of the vitamin B complex, namely thiamine, nicotinic acid, and pantothenic acid. They have also shown that a complicated system of enzymes is required in the conversion of the acid to carbon dioxide and water, involving a synthesis of C_2 fragments to form a C_6 tricarboxylic acid as an intermediate stage. Since pyruvic acid is a half-way stage in the degradation of sugar, it is not surprising that failure in the metabolism of pyruvate is attended by dire consequences in the brain, which is mainly dependent for its normal functioning upon the energy derived from the glucose brought to it in the blood stream. Though much remains to be done, knowledge has now advanced enough to enable us to make a limited analysis of the biochemical lesion in some toxic states; by this is meant the first deviation from normality in the tissue. In this short review it is proposed to show how the existence of a lethal synthesis has been unravelled in connection with the toxic action of a plant poison.

The substance fluoroacetic acid, $F.CH_2.COOH$, has a remarkable historical background; it was first known in chemistry from the synthesis by Swarts at Ghent in 1896 [1]. For over forty-five years no one suspected that it was also a natural product, but in 1943 Marais [2] found that it was the toxic principle of the South African poisonous

plant *Dichapetalum cymosum*, known locally as *Gifblaar* (figure 1); in other words nature had carried out its synthesis long before man. Marais' brilliant isolation was the culmination of several earlier attempts [3].

Dichapetalum cymosum is largely confined to the Pretoria region of South Africa, and the plant flourishes there on particular slopes; twice a year the fresh leaves are so poisonous that 20g are sufficient to kill a sheep. The poison is water-soluble. Eradication of the plant is difficult owing to the extensive, branching, underground-stem system; it is apt to grow among rocks, and it has been necessary to erect fencing to keep cattle from the weed [4]. It is clearly of agricultural importance to try to obtain an antidote. As the action of the fluorine compound is very subtle, it became necessary to conduct a deep biochemical analysis of this action, which will be considered here before its application to the pharmacology.

It so happened that in 1941 some observations were made on both sides of the Atlantic upon the action of this poison upon enzymes, as a purely defensive measure. These revealed the curious fact that, unlike arsenicals, iodoacetate and some other poisons, fluoroacetate had no action upon isolated enzymes. Its toxicity cannot be due to the liberation of fluoride ion because of the extreme stability of the CF bond, withstanding as it does the action of hot concentrated sulphuric acid [5], and there is no evidence as yet of any enzyme in the higher animals that can break this bond. Further knowledge of the action of this toxic agent was imperative (a) if the hope were to be fulfilled of getting an antidote for the poisoned cattle, (b) because it formed a marked exception to the rule that poisons attack enzymes, and (c) because of its probable scientific and medical interest.

When the writer returned to the study of this

poison with C. Liébecq in 1947, two significant facts were available [6]. First, from an extensive research with varied synthetic organic compounds containing the CF bond, B. C. Saunders and his colleagues [7] had concluded that the active entity was $\text{FCH}_2\text{CO}-$; for instance, straight chain compounds containing 2, 4, 6, 8 C atoms were toxic, whereas 3, 5, 7 C and so on were relatively non-toxic. It was somewhat like the well known Knoop rule for the fatty acids. Secondly, Bartlett and Guzman Barron [8], though they could not find any effect upon isolated enzymes, had noticed an accumulation of acetate in poisoned slices of tissue, from which they concluded that the fluoroacetate inhibited acetate oxidation competitively. We soon found, in poisoned particle-preparations from kidney, conditions in which there was a lowering of oxygen uptake with no change in acetate concentration; the enzyme preparations were reinforced, as is customary in this type of work, with adenosine triphosphate and magnesium, and were given fumarate as the substrate.

It was clear, therefore, that Bartlett and Barron's hypothesis was not the whole story. Further

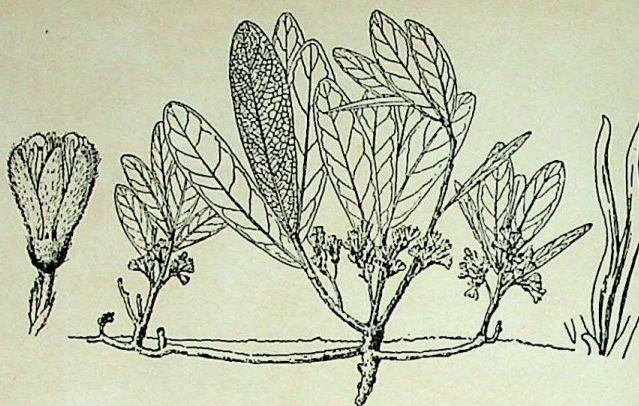


FIGURE 1 - *Dichapetalum cymosum* (Gifblaar), showing the underground stem system. (From Burt Davy.) (Proc. Roy. Soc. B., 139, 143, 1952.)

search brought to light the fact that an accumulation of citrate accompanied the decrease in oxygen uptake. We were thus led to advance the hypothesis in 1948 [6] that the fluoroacetate behaved somewhat like acetate in metabolism, that it was transformed by the reactions of the tricarboxylic acid cycle to form a fluorotricarboxylic acid, which then jammed oxidation of citrate. Figure 2 illustrates very diagrammatically the final course of the oxidation of the C_2 fragments derived from pyruvate, and figure 3 the 'jamming' hypothesis. A similar view was put forward independently a little later by Martius [9]. The idea that the citrate accumulations were an important factor of the poisoning was considerably strengthened when it was found by P. Buffa and the writer [10] that

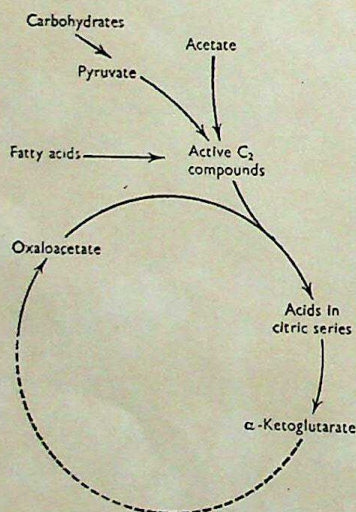


FIGURE 2 - Diagram of main stages in tricarboxylic acid cycle (see Krebs, 'Advances in Enzymology,' Vol. 3, 1943). Pyruvate, after decarboxylation and activation to a C_2 fragment (now known to be acetyl-coenzyme A (Lipmann)), condenses with the C_4 acid, oxaloacetic acid, to form the C_6 acid, citric acid. By degradation to a C_5 acid and then to C_4 acids, oxaloacetic acid is again regenerated. During the degradation CO_2 and H_2O are eliminated, thereby completing oxidation of the C_2 fragment. The biological reason for these complications is unknown.

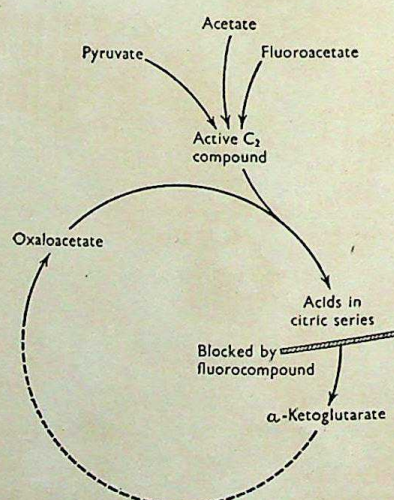


FIGURE 3 - 'Jamming theory.' After activation to a C_2 fragment fluoroacetate is condensed to form fluorocitric acid, which then 'jams' further degradation of citric acid.

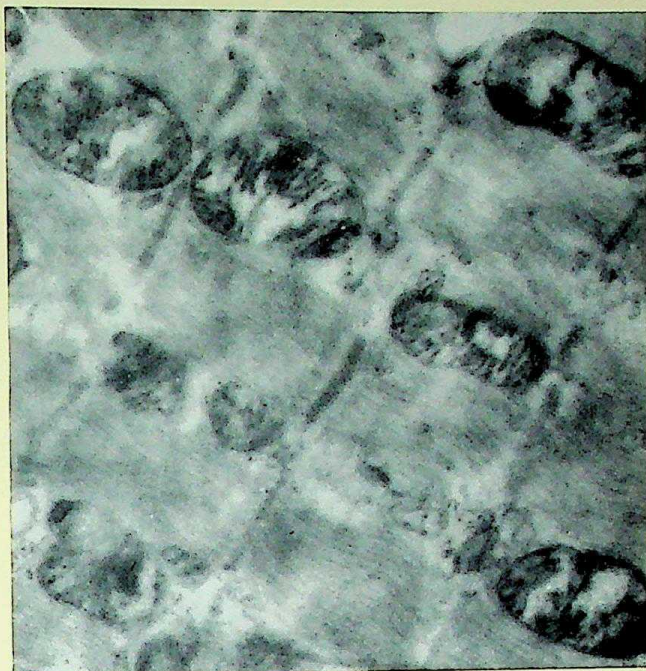


FIGURE 4—Electron micrographs of mitochondria (*J. Histochemistry and Cytochemistry*, 1953, I, 188); section cut by the microtome described by A. Claude, *Harvey Lectures*, 1948, XLIII, p. 152; approximate thickness less than 0.05μ . The tissues were fixed in buffered osmium tetroxide at pH 7.3 and embedded in polymerized methyl methacrylate. Left: rat kidney mitochondria ($\times 22,850$). Note the fine structure, especially the internal ridges (cristae mitochondriales) protruding towards the interior of the organelles. There is a membrane present about $7 m\mu$ ($70 \text{ \AA}$) thick. Right: rat myocardium ($\times 22,500$).

(Photographs by G. E. Palade, Rockefeller Institute.)

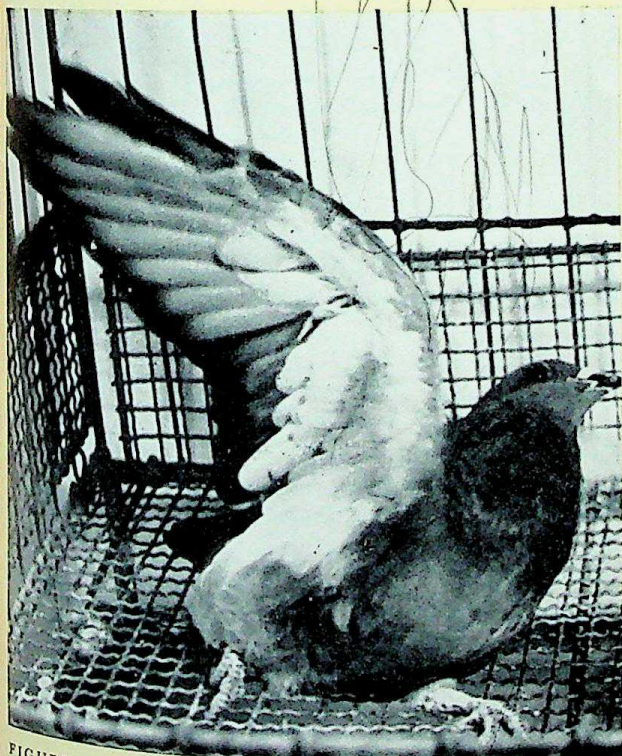


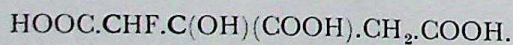
FIGURE 5—Beginning of a fit due to the intracranial injection (under ether anaesthesia) of fluorocitrate. (*Brit. med. Bull.*, 9, 116, 1953.)

FIGURE 6—Crystalline specimen of fluorocitric acid. (*Proc. Roy. Soc. B.*, 140, 497, 1953.)



FIGURE 7 - *Dichapetalum toxicarium* (p. 153). Photographs of dry drupe (the nut-like fruit containing the seeds) and of the separated seeds. (Natural size.)

fluoroacetate poisoning *in vivo* leads within the short time of 30-60 minutes to remarkable accumulations of citric acid in various organs: in kidney this may be 80 times the normal, in heart 20 times, in brain 8 times. The effects are evidently general; they have been demonstrated in the rat, mouse, rabbit, guinea-pig, dog, and pigeon. The fact that there are no increases in the concentration of pyruvate or of α -ketoglutarate limits the action definitely to the tricarboxylic acid stage of the cycle. It was clear that progress could be made only by isolation of the fluoro-compound, if it existed, especially since by this time others had found the increase in citric acid *in vitro* and were suggesting that it was due to an increased formation rather than a decreased oxidation [11]. When we embarked upon it, we little realized that it would take us four years to prove that the compound synthesized enzymically was actually the new compound monofluorocitric acid:



Some remarks upon the details of the isolation will indicate the special difficulties encountered. The best way to make the inhibitor was to syn-

thesize it with kidney particles in a phosphate-potassium chloride medium from fumarate and fluoroacetate. Attempts to do this on a really large scale with ox kidney failed, so that the tissue used came mainly from the guinea-pig and rabbit, and occasionally from the kidneys of dogs. Preparations were tested by using centrifuged kidney particles (from guinea-pigs); the capacity of a supposed fluorocitrate fraction in stopping the removal of citric acid in 30 minutes at 38°C formed a basis of comparison for isolation. The kidneys of one rabbit made about 1 mg of fluorocitrate; this had to be separated from much larger amounts of citrate and phosphate. We were much misled for months by failure to realize how little fluoro-compound was causing the inhibition. Eventually, by finding, first, that the required inhibitor was more acidic than phosphoric and citric acids and that, therefore, it would be precipitated at a lower pH with lead salts, and, secondly, that it required a stronger acid to remove it from a column of amberlite resin (IRA 400) than citric or the last traces of phosphoric acid, fluorocitric acid was separated in small amounts (7 mg) as a crystalline and very hygroscopic compound (figure 6) [12, 13].

The presence of a CF compound was demonstrated by infra-red spectrometry, and the fluorine content was estimated spectrochemically in the special bands for F, viz. 7128 Å and 7200 Å respectively [14]. The latter method is new and very powerful; it not only makes the presence of fluorine certain, but is capable of estimating as little as a few µg of it. The final proof that the compound was a citrate (rather than an isocitrate) depended upon a synthesis of fluorocitric acid by Rivett and comparison of the spectra [15].

The fluorocitric acid synthesized by the enzymes is a very potent inhibitor of citric acid metabolism in the kidney particles: to make this precise, the effect of less than 1 µg can be determined in the presence of 1.92 mg (10 µmol) of citric acid. It can be seen from the formula that there should be four stereoisomers present in the synthetic specimens. From this it might be inferred that the synthetic compound would be less active than the natural; experiments show that it has about 50 per cent of the activity, suggesting that only one of the optically active C atoms matters for the inhibitory activity.

Our next inquiry must be whether there is proof that the enzymes concerned with the tricarboxylic acid stages of the cycle are inhibited. It will be seen from figure 8 that only two enzymes are likely to be concerned, aconitase and isocitric dehydrogenase. The latter carries out the change of the C₆ compound, isocitric acid, to the C₅ compound α-ketoglutaric acid, and is not affected by fluorocitric acid [12]. This reduces the problem to that of the behaviour of aconitase. This remarkable enzyme is a most appropriate tool for this stage in metabolism because, by its action in altering the position of the OH group, it prepares the way for the subsequent decarboxylation of the α-keto compound. Until recently, the instability of this enzyme has been a difficulty in research, but taking advantage of the findings in Sweden that citric acid can stabilize it, and in the U.S.A. that ferrous iron and cysteine are needed for full activity [16], it has recently been tamed in the writer's laboratory [17]: purified preparations will remain stable for months in the cold. With this isolated and soluble enzyme it has now been established that the natural fluorocitric acid is a competitive inhibitor [18], thus bearing out preliminary indications [19]. This can account for the observed inhibition;

but, as often happens in research, certain subsidiary facts have appeared that are not yet properly understood.

The particle-preparations from kidney that have been used for the inhibitor tests are 10–20 times more sensitive to the effect of the fluorocitric acid than is the soluble aconitase enzyme. This leads one to ask what are the differences of constitution of these particles; recent research (started by Bensley and continued by Claude, Hogeboom, Schneider, and others) has elucidated the fact that the preparations of particles obtained in this way are in fact preparations of the mitochondria from the insides of the tissue cells. These mitochondria (perhaps 2 µ long and 0.5 µ wide) are evidently the seat of activity of the enzymes oxidizing pyruvate, which include the enzymes of the tricarboxylic acid cycle. Indeed, there have been experiments done recently in the Rockefeller Foundation in which photographs with the electron microscope show a somewhat highly organized structure in the mitochondria (figure 4). In the cell, therefore, the enzymes concerned are, as it were, shut up in these mitochondrial bags. We are dealing, in particle preparations from kidney, with these bags of enzymes, probably structurally organized; at any rate they have a permeability barrier which separates them from the medium in which they are suspended. Somehow these factors are sufficient to magnify the effects observed when fluorocitrate acts upon the aconitase enzyme inside the mitochondrion. How and why these differences occur is still unknown, but a matter of far-reaching significance is probably raised.

The next question to be considered is whether in fact the compound fluorocitrate can be responsible for the lethal effect of fluoroacetate. Some remarks are necessary about the poisoning signs seen with fluoroacetate. The doses required to kill different animals vary very much. The dog is killed by 0.06 mg/kg, whereas the toad will stand doses of 500 mg/kg. In the intermediate range, we

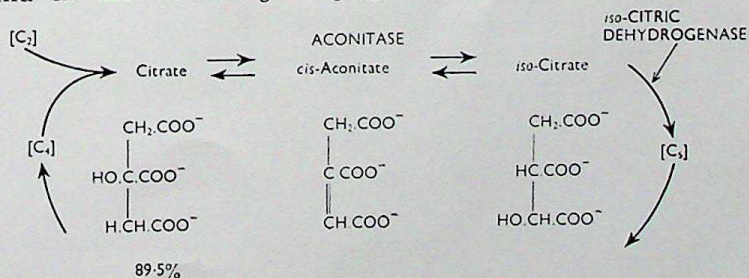


FIGURE 8 – The reactions of the tricarboxylic acid cycle effected by the enzymes aconitase and isocitric dehydrogenase. (Proc. Roy. Soc. B., 139, 143, 1952.)

have the doses for various other animals [20]; for instance, the rabbit will be poisoned by something like 0.2 mg/kg, whereas the rat will require a dose of 5 mg/kg. These strange differences can probably be correlated with different powers of activating acetate, though this matter still awaits a proper proof. The monkey requires a somewhat larger dose, upwards of 15 mg/kg. It seems that man also is relatively insensitive; this was proved by E. D. Adrian, who took a dose sufficient to produce a urine toxic to guinea-pigs. There are two classes of signs found in varying degree in different animals. Some, like the dog, show signs chiefly in the nervous system; others, like the rabbit, are mainly affected in the heart, getting (for example) fibrillation. The rat shows both signs in varying degree. After lethal doses there is usually a period of delay of about 20-25 minutes. The animal then appears to be worried and shortly afterwards may go into a rigid tetanic convulsion.

It has been possible recently to prove that the fluorocitrate is itself the toxic agent by injecting it, under ether, within the skull of the pigeon. After an injection of some 30 µg of enzymically prepared fluorocitrate, the animal comes round from the anaesthetic and is normal for a short period of ten minutes or so; it then becomes agitated and finally enters upon convulsions having some resemblance to those produced by thiamine deficiency, though usually there is more wing movement to be seen (figure 5). The fits kill the animal quickly. As little as 11 µg of fluorocitrate has sufficed to throw an animal into such a condition. On the other hand, an intracranial injection of fluoroacetate in larger amounts gives no convulsions at all. This fact is consistent with the indirect evidence that brain tissue does not synthesize fluorocitrate from fluoroacetate, and suggests that convulsions occurring after intraperitoneal injections of fluoroacetate are due to penetration to the brain by fluorocitrate synthesized elsewhere. Since these fits can be induced by fluorocitrate, it is, in the writer's opinion, definitely proved that in fluoroacetate poisoning there is a lethal synthesis brought about by the action of the body's own tissue enzymes.

The research has demonstrated two things fairly clearly. First, the citric acid cycle must be a reality *in vivo*. Secondly, though this appeared to be an exception to the general proposition that toxic substances poisoned intracellular enzymes, now it is seen to fall into the general rule. Several other questions are left that are worth discussion. First, what is the mechanism by which these con-

vulsions are produced, and is there any chance of reversing them? [21]. Secondly, supposing we are unsuccessful in reversing them, can we protect the animals by stopping the synthesis of fluorocitrate in some way, and so avert the toxicity? Thirdly, arising out of this, is there any other possible medical application? Finally, when all these points are settled, a further question arises, namely whether there are any other examples of this type of lethal synthesis.

These questions will be dealt with in order. In considering what causes convulsions, two thoughts immediately occur; the first is that stopping pyruvate oxidation at the stage of citric acid must cut off the energy supply to a large extent. In other examples of interference with pyruvate oxidation in the pigeon brain, rather similar signs appear, e.g. in thiamine deficiency and arsenical intoxication; further, a reduction of sugar in the blood by cutting off the sugar supply with insulin also leads to convulsions. In all these cases there is an interruption of the energy supply sufficient to throw some parts of the brain out of order, so causing the dysfunction which is reflected in the signs observed. In the case of the fluorocitrate-induced fit there is, secondarily, a further possible factor of complication. The increasing amount of citrate might be expected, quite reasonably, to interfere by combination with any calcium concentration in the tissue. It has been well known for many

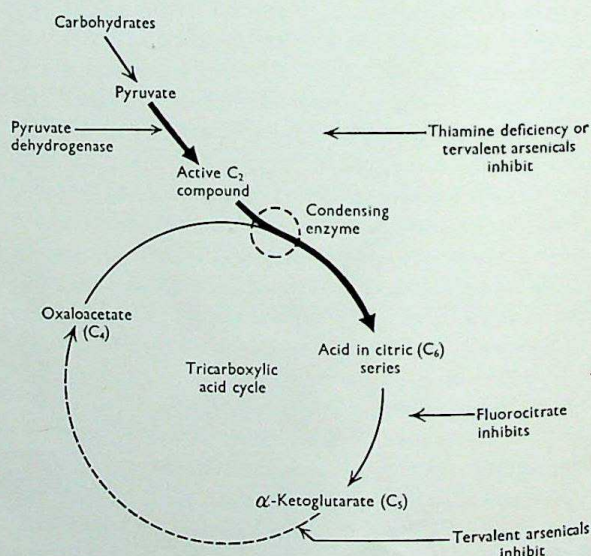


FIGURE 9 - Diagrammatic representation of the course of oxidation of pyruvate by the pyruvate oxidase system, showing the stages at which vitamin B₁ (thiamine) deficiency, tervalent arsenicals, and fluorocitrate respectively stop the oxidation. Each of them can induce fits. (Brit. med. Bull., 9, 116. 1953.)

years that interference with the calcium concentration which bathes the nerves will induce a hyper-excitable state; for instance, Hastings and colleagues [22] have shown that a decrease in the concentration of calcium in the cerebro-spinal fluid is enough to cause convulsions in dogs, and these convulsions may be stopped at once if the calcium bound by the injected citrate is replaced. There is a difference in the site of citric acid accumulation in fluorocitrate poisoning, because this accumulation occurs inside the cells and not in the medium that is bathing them. One authority considers that the amounts of Ca^{++} , if any, inside cells are negligible [23]. Some extensive experiments with pigeons and also with rabbits have led to the conclusion that it is impossible to reverse these fits by injection of calcium [24]. As yet, therefore, there is no experimental evidence that they are due to interference with the balance of inorganic ions. This whole question is still *sub judice*. It has been found that there is no direct correlation between the citric acid accumulation and the convulsive state. This would not be expected on physiological principles. It has also been shown that in one animal at least, namely the horned toad, large accumulations of citrate can occur in the heart without apparent disturbance of function [25], facts which are difficult to interpret. They might merely mean that the calcium injected into the cerebro-spinal fluid does not penetrate the barrier and get at the site which is poisoned by fluorocitrate. What can be definitely stated is that the action of the fluorocitrate upon aconitase induces the biochemical lesion which starts the neurones concerned upon the path leading to hyper-excitability.

With regard to the chances of reversing these signs, and so curing the animal, which was one of the purposes of the research, neither we nor others have had any success with injection of members of the tricarboxylic acid cycle. It might well have been expected that some of these acids might cure by displacing the fluorocitrate. It is not known whether this failure is due to the difficulty of penetration to the active site; but at the moment this line of approach has failed, and recourse has had to be made to protection rather than to reversal of the condition once it has become established. After the early work done with acetate, various attempts were made to reduce the severity of the conditions, either with acetate or by injection of C_2 substances such as alcohol. These substances have had only a limited success except in one case: Chenoweth and his colleagues [26] found that

glycerol monoacetin would avert death when injected shortly after a lethal dose of fluoroacetate. This they believe to be due to the presence inside the cell of the C_2 fragment introduced by the glycerol carrier. A somewhat similar explanation has been given by Gitter, Blank, and Bergmann [27], who used acetamide for protection with similar success.

These results suggested that it should be possible to fill the logical gap in the biochemistry by showing that C_2 substances stop the formation of fluorocitrate from fluoroacetate *in vitro*, and this has been done in our laboratory: small amounts of acetate will stop the synthesis *in vitro* from relatively larger amounts of fluoroacetate.

POSSIBLE MEDICAL AND SCIENTIFIC APPLICATIONS

The possible medical and scientific applications of the facts described centre round interference with the metabolism of pyruvate in general, and at the aconitase stage in particular, with its indicator of increased citrate concentration (figure 9). It may be noted that the increase in citric acid induced may be expected to have forensic application in providing non-symptomatic evidence in confirmation of suspected fluoroacetate poisoning. Beyond thiamine deficiency and arsenical poisoning, the only other instance known at present of an agent which produces interference with pyruvate oxidation coupled with objective medical signs is that of the alkaloid sanguinarine, associated with the seeds of *Argemone mexicana* and a contaminant of mustard oil [28]; there is a strong possibility that this may be responsible for epidemic dropsy. Regarding interference at the citric acid stage, we still know little, but it is probable that a search would produce clinical applications.

In the fluorine field, some progress has been made in the writer's laboratory [21] towards the isolation of the active principles from another species, *Dichapetalum toxicarium*, also called ratsbane; this plant, found in the Sierra Leone district, has been used by witch-doctors, and produces the condition known as 'broke back,' strongly resembling a neuronitis (figure 7). We have proved that injection of extracts of the seeds induces citric acid accumulation *in vivo*, and small amounts of fluorocitrate have been isolated, indicating the close connection with the observations made upon the active principle of *Dichapetalum cymosum*. In this instance a direct medical application is in sight in the sense of an understanding of the underlying biochemical causation of 'broke back.'

CLOSING REMARKS

To sum up, though the deep biochemical analysis briefly described has indicated what must be done to reverse the poisoning, it has also shown clearly that this is made specially difficult by the necessity of penetrating into the mitochondrion without disturbing its organization. Nevertheless, the protective effect of C_2 -containing substances can now be logically explained as due to interference with the synthesis of fluorocitrate. This research leaves little doubt of the reality of the citric acid stage of the tricarboxylic acid cycle *in vivo*, which the work of Krebs and others has done so much to establish *in vitro*. There is now a new agent for inhibiting the cycle reactions *in vitro*, as well as a selective inhibitor for aconitase. There is also now available another convulsive agent inducing a biochemical lesion which is understood in principle and which should therefore prove a useful tool in studying the initiation and cause of some fits. Again, one instance has been thrown into relief in which a 'mitochondrial' enzyme behaves differently from the same enzyme in solution; this may prove of far-reaching importance. It is the writer's opinion that the above dividends have come from conducting this type of biochemical analysis; it was used in the arsenical and British anti-lewisite researches and, though it is slow, the writer believes it to be the best

hope of advancing the cause of logical therapy.

The lethal synthesis revealed and proved here for the first time has to be distinguished from toxic conversions such as occur with arsenical drugs, because a piece of the body's enzymic machinery is used to make a toxic substance; if nothing were done to the fluoroacetate, it would be innocuous. It is therefore the opposite of the well known instances of protective synthesis where a potentially toxic molecule has its toxicity much reduced by coupling with glycuronic acid or other such substance. It is what one would like to do with a cancer if a knowledge of its metabolism would show up some difference of which advantage could be taken. It is likely to prove a more general phenomenon, and at least one analogous case has appeared in the insecticides, where a compound initially non-inhibitory to the enzyme cholinesterase becomes so when injected. The real puzzle is how living matter can continuously protect itself against more happenings of this character, and, as always, the deeper the research the more does our respect grow for the conditions under which life becomes manifest.

NOTE. The author is indebted to Sir John Simonsen, Dr Galley, and the Director of Njala Station for the seeds of *Dichapetalum toxicarium*. He also wishes to thank Dr Claude, Dr Palade, and the 'Journal of Histochemistry and Cytochemistry' for the micrographs reproduced in figure 4.

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Reaction paths in plant respiration

W. O. JAMES

While much still remains to be discovered about the respiratory mechanisms of particular species of plants in particular circumstances, the general biochemical pattern of plant respiration can now be discerned, and proves to possess a striking resemblance to that found in other types of organism. In this article, Dr James reviews some of the principal reaction-paths that have been established, and assesses their relative importance under various conditions.

The idea that has dominated the biochemical study of plant respiration for some seventy years was first put forward for animal tissues, and began from the observation that many tissues—probably all plant tissues—continue to give off carbon dioxide when they are deprived of oxygen. It was clear that metabolic changes akin to a fermentation went on, at least for a while, in the total absence of oxygen.

It would not be extravagant to regard these anaerobic changes, which include a redox reaction, as a sort of basic respiration, and the additional oxidation in the presence of molecular oxygen as a refinement improving efficiency at the expense of increased elaboration of machinery. It is even possible to regard these two stages as showing an actual evolutionary advance from a primitive condition of life in an airless world to a level made possible by the advent of oxygen. The case has been eloquently pleaded by Oparin [1].

There was, in fact, nothing novel in the idea of anaerobic metabolism by 1878, when Pfeffer applied it to the higher plants. The period coincided with the studies of Pasteur on yeast, and great interest attached to the observation that alcohol appeared to be formed in the tissues. Pasteur himself distilled alcohol from a number of succulent fruits, such as plums, subjected to varying periods of deprivation of oxygen. The question arose whether the alcohol had truly been produced by the mesocarp of the fruit, or whether it might not rather have been formed by epiphytic yeasts. Pasteur thought not, but it is a matter of great difficulty to maintain sterility over so long an anaerobiosis, and Pfeffer and others later expressed doubts about these early experiments. Subsequent investigation has largely aimed at clearing up three points: firstly, the authentic origin of the anaerobic product from plant tissue as distinct from microbial intruders; secondly, the correctness of its identification as alcohol; and, finally, the extent of its formation.

The earliest experimenters sought to exclude alcohol of microbial origin by cutting out deep-seated samples of tissue for analysis. The only plant tissues that can be rigidly sterilized without destroying them are dormant seeds protected by thick non-living coats, and the device has therefore been used of introducing sterilized seeds into sterilized vessels and germinating them in the enclosure. Some oxygen must be present at first or germination fails, but it can be withdrawn after a few days. Recently, the problem has been simplified by the use of antibiotics; streptomycin, if combined with a normal degree of cleanliness of apparatus, will keep the surface of carrot tissue, for example, free from significant contaminations for several days.

The earlier identifications of alcohol in plant tissues depended on volatility, smell, the iodoform test, and the smell of ethyl benzoate. Phillips [2] achieved some improvement by comparing the refractive index of distillates with their dichromate-reducing power, and her results with preparations from barley seedlings agreed to within 3 or 4 per cent. The principal obstacle to satisfactory identification by normal chemical methods lies in the fact that the alcohol is produced in the presence of a large excess of water. Since reaction with 3,5-dinitrobenzoyl chloride to obtain a conveniently characterized ester occurs only in the absence of water, separation and drying become necessary but tedious processes attended by much loss. Adequate quantities of the ester have now been prepared with alcohol derived from barley seedlings, apples, carrots and other plant tissues [3].

The common theory of alcohol formation in higher plants has always been moulded on that for yeast, although other reaction paths are known, for example in *Escherichia coli*. It is assumed that the equation $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ will be obeyed, except so far as it may be disturbed by side-processes or accumulation of intermediates.

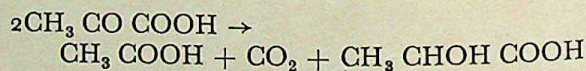
Its quantitative investigation in higher plants is more difficult than in yeast, because the sugar to be determined is an unknown mixture within the tissues instead of a simple known addition. Only quite recently has the attempt to relate amounts of sugar consumption and alcohol formation been seriously made—or, indeed, become possible with increased refinements in the micro-analysis of sugars. Failing such means, the earlier workers, notably Palladin and Kostychev, concentrated their attention on the relative amounts of alcohol and carbon dioxide formed. Although the ratio 1 : 1 is required by the equation, its occurrence would do very little, without simultaneous knowledge of the loss of sugar, towards proving it. Known biological products of sugar-breakdown, like lactic acid and glycerol, need cause no disturbance in the ratio of alcohol to carbon dioxide. This could quite well result from a trifling side-reaction rather than from the main course of events. As it turned out—rather fortunately—the predicted value of unity was obtained only with a minority of tissues, which included germinating peas and rice, and storage carrots. Other results all showed an excess production of carbon dioxide over that of alcohol, but the causes of this excess are still largely a matter of conjecture.

In 1903, Nabokich [4] found that the alcohol to carbon dioxide ratio for germinating peas lay very close to unity, the values in seven separate experiments varying only from 1.03 to 0.96. He also determined the loss of solids by weighing the dried residues. On the assumption that the whole of this loss was due to breakdown of starch, he was able to calculate the 'hexose' consumption and compare it with the weight of alcohol plus carbon dioxide recovered. The mean of the recoveries fell only 2 per cent short of the calculated mean consumption.

Carrot tissue has been investigated more specifically. Values close to unity have been repeatedly obtained for the molecular ratio of the products, and only the simple, soluble sugars appear to be broken down during two or three days of aseptic anaerobiosis. Recent analyses using the Somogyi technique have shown a loss of sugar, calculated as weight of hexose, little if at all in excess of the recovery of alcohol and carbon dioxide. At the same time it has been found that no considerable amounts of acetaldehyde, glycerol, phosphate esters, lactic acid, or other carboxylic acids accumulate [5]. The anaerobic respiration of this tissue appears, indeed, to be a near approximation to a simple alcoholic fermentation.

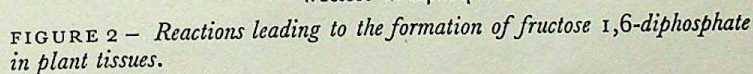
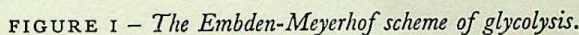
It is interesting to find that at least some plant tissues promote a known and relatively simple series of reactions, but this cannot be the whole of the story; some are known to consume other materials besides sugars. Apples accumulate malic acid in the early stages of their development, and steadily consume it during slow ripening in cool storage. Fidler [6] has shown that the rate of consumption is not altered by the absence of oxygen over long periods. The alcohol to carbon dioxide ratio varies considerably, never exceeding unity, and sometimes falling as low as 0.4. The excess carbon dioxide could be more or less quantitatively accounted for by the supposition that malic acid continues to be fully oxidized to carbon dioxide in an atmosphere of nitrogen, but this rather difficult assumption has not yet been substantiated.

The recently published studies of Barker and El-Saifi [7] on potatoes illustrate another type of variation. Carbon dioxide continues to be given off in an atmosphere of nitrogen, but only at a reduced rate. No alcohol appears unless the tubers are cut, sliced, or otherwise damaged, but there is a steady accumulation of lactic acid. The free sugars of potatoes are constantly replenished from the vast excess of starch, and it is unfortunately not possible to determine the actual sugar-loss for comparison with the amount of lactate appearing. It is, however, clear that this accounts for only a relatively small part of the whole anaerobic respiration, because some carbon dioxide continues to come off, and alcohol-soluble solids not yet identified accumulate to about the same weight as the lactic acid. Simultaneous formation of carbon dioxide and lactic acid without alcohol might result from the dismutation



as carried on by some bacteria and, it is claimed, by tomato stems [8]. When the potatoes were transferred to nitrogen, the ratio of carbon dioxide and lactic acid productions followed opposite instead of parallel courses. While the rate of lactic acid formation accelerated the rate of carbon dioxide release fell away, and the evidence must be taken to show that the unknown products and the carbon dioxide come not from the above, but from some still unidentified reaction. After prolonged deprivation of oxygen, or if the cells are mechanically injured, the restriction on alcohol-formation disappears and alcohol accumulates

Metabolites other than carbohydrates and plant acids are not normally consumed in plant respiration, and this may be true in the absence of oxygen as well as in its presence. Some at least of the variations of anaerobic respiration, lactate formation in particular, are closely related to alcoholic fermentation and may be regarded as deflections of a common reaction path. So far as carbohydrate-breakdown is concerned—and this is almost certain to be the main process—there appears to be a remarkable similarity of reaction mechanism in organisms of all kinds. However much the final products may be made to differ by side or subsequent reactions, the initial attack adheres to a common type characterized by phosphate catalysis. The details of this complex reaction sequence, as revealed in yeast and muscle, are now too familiar to need description here; figure 1 provides a synopsis. Two stages may be recognized: first the phosphorylation culminating in the synthesis of hexose- (fructofuranose-) 1,6-diphosphate, and then the glycolysis ending with pyruvic acid. The carbohydrate phosphorylated may vary; it is commonly either starch or sucrose in the higher plants; more rarely a hemicellulose, a fructosan, or raffinose; even glycosides or fats may be pressed into service by one tissue or another. The range in the saprophytic fungi may be even wider, and, although glucose is the common sustenance of yeast, other carbohydrates also are attacked; among bacteria it would be difficult



to set the limits. Whatever the source of the hexose units, the product of anaerobic phosphorylation is likely to be hexose-diphosphate. All the reactions indicated in figure 2 have now been identified in plants.

The kinetic relations within healthy plant tissues are such that hexosediphosphate does not accumulate. It may, however, be caused to do so in cell-free extracts and mushes, especially if they are fed with sugar and adenosine triphosphate (ATP). It would appear a reasonable speculation that the conversion of fructofuranose-1,6-diphosphate to

pyruvic acid is the most uniformly managed of all biological processes. There is a type of organism, exemplified by *Trypanosoma evansi*, that produces pyruvic acid in the conventional way, but, having done so much, troubles itself no further. This interesting economy of metabolic effort is possible only to a parasite living in the bloodstream of a host that will dispose of the inconveniently reactive pyruvate. In more normal organisms the consequences of pyruvic acid formation must work themselves out internally.

The formation of pyruvic acid in respiring barley tissues was shown in 1940 [9]. It appeared in isolable amounts only after its consumption had been retarded by application of an enzyme block, suggesting that formation and disposal were both going on during normal glycolysis. Evidence for the reaction path indicated in figure 1 has since been patiently accumulated [10]. In 1953 Axelrod and Bandurski [11] showed the presence in pea meal of phosphoglyceric kinase, the enzyme catalysing the reaction 1,3-diphosphoglyceric acid + adenosine diphosphate $\rightleftharpoons$ 3-phosphoglyceric acid + ATP. This enabled them to state that all the enzymes of the Embden-Meyerhof scheme of glycolysis have now been shown to be present in higher plants. The essential coenzyme-I (diphosphopyridine-nucleotide) and adenosine phosphates have also been extracted. Though the molecular structures of the higher plant products have not yet been established, functionally they appear to be interchangeable with those from yeast. It can further be added, as a result of experiments with inhibitors such as iodoacetate, fluoride, and aromatic sulphonic acids, that the reactions appear to proceed in the living plant tissues, and that the scheme is actually as well as potentially operative.

The presence of pyruvic acid poses a metabolic problem that has many possible solutions; some of them are indicated in figure 3. The answer most favoured by the higher plants in the absence of oxygen appears to be decarboxylation followed

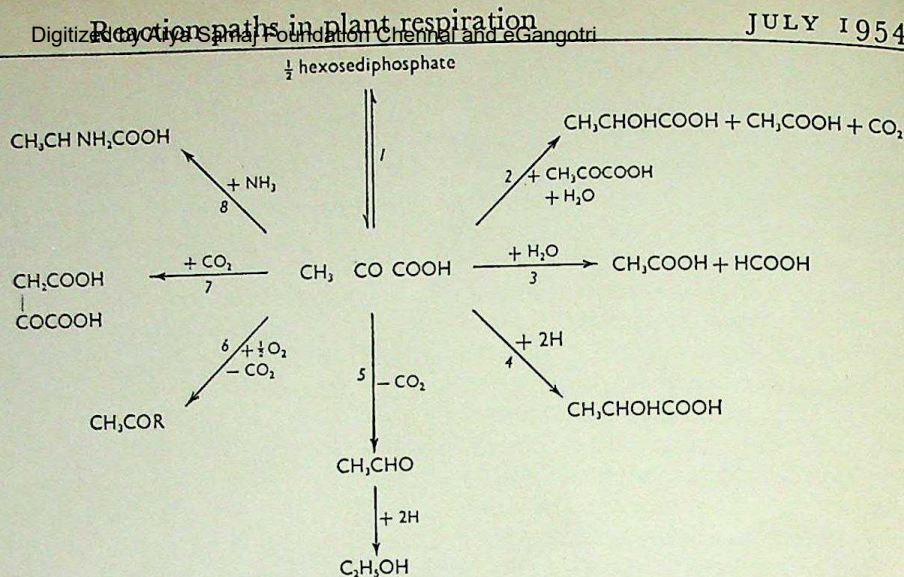


FIGURE 3—Reactions of pyruvic acid in biological systems. Reactions 1, 4, and 5 occur in plants anaerobically; 6 in aerobic respirations; 7 in CO_2 -fixation by plants in the dark; 8 probably in nitrogen metabolism.

by reduction, leading through acetaldehyde to alcohol (5). Suppression or control of the decarboxylation leads to the formation of lactic acid (4). This, the standard reaction in muscle, occurs also (as mentioned) in potatoes, with a ready relapse to alcohol formation in trauma. Lactic acid is known to be formed in other plants, and the extent of its participation in their anaerobiosis is ripe for investigation. Other anaerobic disposals of pyruvic acid, such as occur in some bacterial fermentations, have not yet been observed in higher plants.

The effect of oxygen upon the organized reaction-system of glycolysis is complex and only partially understood. There are two main types of response when tissues are transferred from an atmosphere of nitrogen to one of air, and these are diagrammatically summarized in figure 4. The unbroken line represents the rate of release of carbon dioxide from storage carrots kept in nitrogen. On return to air they show a direct readjustment to their original rate. Potatoes, on the other hand, show a massive increase of carbon dioxide production, which settles back to the normal air line only after a large amount of additional carbon dioxide has come off (figure 4, broken line). As described above, carrots in an atmosphere of nitrogen accumulate only alcohol, which they are unable to oxidize; once formed, it persists in the tissues, even in air. The lactic acid formed by potatoes, on the other hand, is rapidly oxidized by them when oxygen becomes available. While this is going on, pyruvic and other plant

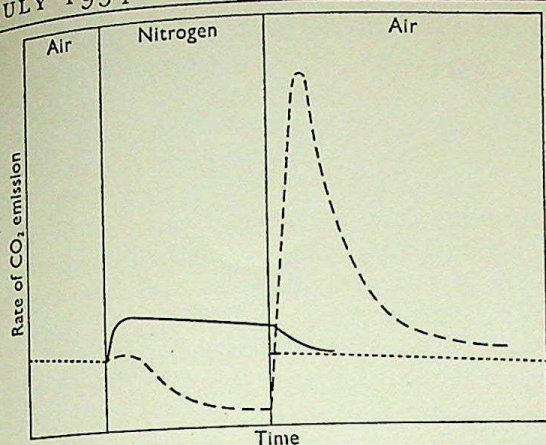


FIGURE 4 - The rate of CO_2 -emission during transfers between air and nitrogen. adjusted rate in air; — carrots removed to nitrogen and back to air; - - - - - potatoes removed to nitrogen and back to air.

acids accumulate to a higher concentration than usual, and are gradually fully oxidized to give the additional carbon dioxide that comes off. The difference of response does not depend upon the reduction-product formed. Some tissues are able to oxidize alcohol, and are then likely to show a post-nitrogen effect like that of potatoes.

The inability of some plant tissues to oxidize alcohol gave rise early to the suggestion that oxidation must intervene at earlier stages of glycolysis. Direct oxidation of sugars to C_6 -acids has never been shown to happen in the higher plants, and its well known occurrence in the mould fungi may be exceptional even within that group. A good deal of familiar physiological and biochemical evidence goes to suggest that oxidation modifies glycolysis rather than supersedes it by directly oxidizing sugars. The almost invariable oxidizer of glycolysis products is coenzyme-I, with the occasional substitution of coenzyme-II (triphosphopyridine-nucleotide). The reactions are catalysed by dehydrogenases, which are highly specific towards the hydrogen donors after which they are named, and absolutely specific towards the acceptor. In some plant tissues hydrogen may be transferred from triosephosphate either to coenzyme-I or to coenzyme-II, but the two reactions are catalysed by separate dehydrogenases [12]. Glycolysis products likely to be oxidized by coenzyme-I are indicated in figure 5. The oxidation of triose phosphate occurs anaerobically, when the catalytic amounts of coenzyme-I present are reoxidized by

transfer of the accepted hydrogen to acetaldehyde or pyruvic acid. When oxygen is introduced it becomes a preferred hydrogen acceptor, and the production of alcohol and lactic acid is retarded or, at above some 5 per cent of oxygen, entirely suppressed. Lactic and alcohol dehydrogenases catalyse their anaerobic reductions; it is doubtful whether they ever get the chance in healthy tissues to catalyse the reverse oxidations, except temporarily after a previous nitrogen treatment. The deflection of the hydrogen transfer, or more exactly the electron flow, to oxygen does not change the oxidation product of the triosephosphate, and the reaction-chain continues unaltered at least as far as pyruvic acid.

The aerobic fate of pyruvic acid and acetaldehyde has posed one of the most difficult problems of plant metabolism. The favourite solution at present is the supposition that pyruvic acid is oxidatively decarboxylated with the formation of acetyl groups in lieu of acetaldehyde. The condensation of acetyl with oxaloacetic acid initiates the Krebs cycle of reactions, in which an acetyl equivalent is totally oxidized and oxaloacetic acid continuously regenerated (figure 6). It has recently been found possible to centrifuge out from plant tissues particles about 1μ in diameter that may be identical with the cytologists' mitochondria. These vigorously catalyse the oxidation of pyruvic acid, and it has been convincingly shown by a variety of techniques that they do this by the Krebs cycle of operations [13]. When, for example, the particles are incubated with ^{14}C carbonyl-labelled pyruvic acid, $\text{CH}_3\text{.}^{14}\text{CO.COOH}$, and any one of the cycle-acids is added as a trap, this rapidly becomes labelled also [14]. It is probable that some at least of the necessary enzymes exist only in the particles, and that the cycle could not operate in phases of the protoplasm outside them.

The evidence is now good that the cycle actually

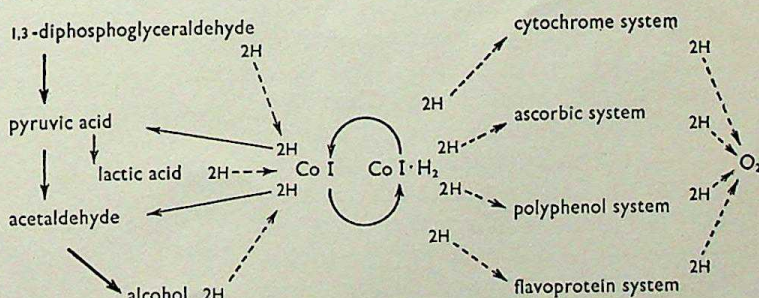


FIGURE 5 - Reduction and oxidation of coenzyme-I. Thin black arrows indicate anaerobic transfers of hydrogen, arrows with broken lines indicate aerobic transfers.

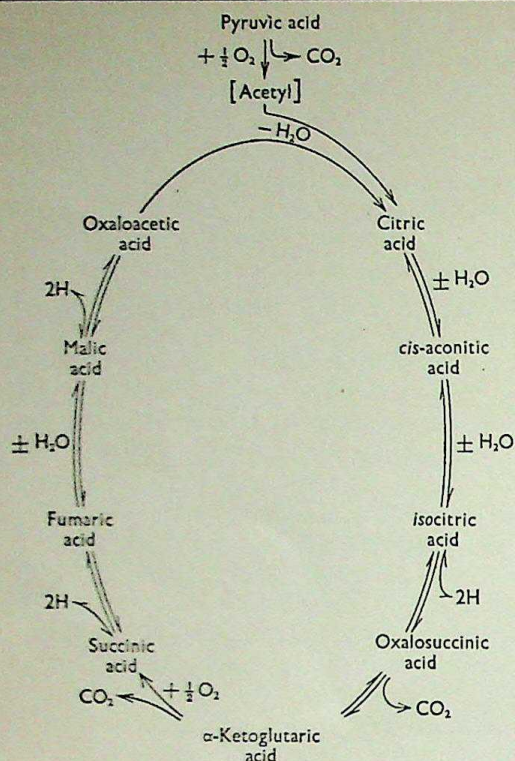


FIGURE 6 - Principal reactions in the oxidation of pyruvic acid by the Krebs cycle.

operates in at least some plant tissues, and that it revolves fast enough to account for their respiration. This hypothesis is so seductive that objective appraisal is not easy. Not only may it dispose of an otherwise awkward respiratory situation, but it also accounts for the presence of many of the plant acids and, perhaps most appealing of all, it forges a credible link between carbohydrate and protein metabolisms by providing the most suitable α -keto acids for amination.

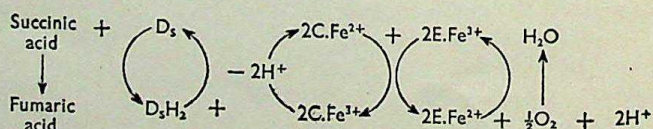
Most of the available evidence points, strictly speaking, only to the occurrence or possibility of the reactions, and gives no indication whether they go fast enough to provide a major respiratory pathway. They might represent an important metabolic sequence even if too slow to catalyse respiration, and, according to Krebs [15], this situation arises in yeast. Among the higher plants there is a dilemma, unresolved at the moment of writing, that may lead to the same conclusion for some plant tissues. Hackett and Simon [13] have isolated a particulate preparation from *Arum* spadix that vigorously promotes the oxidation of pyruvic acid, apparently by the Krebs mechanism; yet the respiration of the same tissue presents

characteristics that make it very difficult to believe that it is catalysed by the same system [16].

Among higher plant tissues that may be cited as using the Krebs cycle as a respiration mechanism are spinach leaves [17] and germinating barley embryos [18]. The respiration of the latter is accelerated by additions of succinic, fumaric, and α -ketoglutaric acids, especially if accompanied by pyruvic acid after about 20 h of previous starvation. Malonic acid inhibits at low pH, and subsequent addition of fumaric acid largely restores the oxygen consumption. Fluoroacetic acid also inhibits heavily and causes the accumulation of citric acid in the tissues by jamming the initial stages of the cycle, as elucidated by Peters with animal preparations. 2,2'-Dipyridyl also strongly inhibits the respiration of these tissues. It has no effect on the anaerobic stages or on the oxidation enzymes, but does inhibit aconitase, the enzyme catalysing the equilibrium between citric, *cis*-aconitic, and isocitric acids in the cycle. It has been shown with spinach leaves that malonic acid poisoning leads to the accumulation of succinic acid [17]. Since, when these things happen, the respiration of the tissues is heavily curtailed, it is reasonable to assume that the reaction cycle is here an effective respiratory agent.

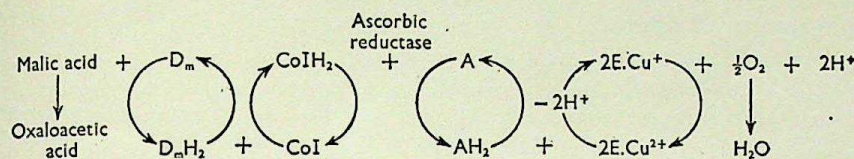
Transfer of hydrogen from the cycle-acids is more variable in its direction than is transfer from the glycolytic donors. Malic dehydrogenase transfers hydrogen to coenzyme-I; isocitric dehydrogenase prefers coenzyme-II, and succinic dehydrogenase uses cytochrome. All three occur only in catalytic amounts, and continuous oxidation requires their regeneration by electron-transfer to atmospheric oxygen. The four redox systems in figure 5 are known to exist in plants and would appear to be capable of catalysing these transfers; they have in fact been induced to oxidize the reduced coenzymes after extraction.

The shortest oxidation chain, and one of the best authenticated as occurring in plants, catalyses the oxidation of succinic acid to fumaric by the cytochrome system, which apparently eliminates the coenzymes. It may be represented



writing D_s for succinic dehydrogenase, C.Fe^{2+} for reduced cytochrome, and E.Fe^{2+} for reduced cytochrome oxidase.

The oxidation of malic acid by coenzyme-I, and that of isocitric acid by coenzyme-II, introduce a further enzyme, cytochrome reductase, which catalyses the transfer of electrons from the coenzyme to a cytochrome. Similar oxidation chains have been extracted from plants and assembled *in vitro* using ascorbic acid and oxidase, or a polyphenol and polyphenol oxidase. Malic acid oxidation through the ascorbic system as extracted from plants may be written



Ascorbic acid is here written AH_2 and reduced ascorbic oxidase as E.Cu^+ .

The possibility of reconstructing these systems *in vitro* does not necessarily prove their activity inside the tissue. According to present information, the most important redox chain in plant respiration is the cytochrome system. Convincing evidence of its activity in seedling and some other tissues has been obtained, and it probably catalyses at least four-fifths of their respiratory oxygen consumption. This conclusion rests mainly on the evidence that the system may be extracted from such tissues, that the characteristic absorption bands may be seen to fluctuate appropriately with the redox conditions imposed on the tissues, and that the respiration is heavily inhibited by dilute cyanide. Finally, and most conclusively, the respiration suffers an inhibition by carbon monoxide which is reversed by visible light of short wavelength.

Present information is, however, rather scanty, and it would be rash to assume that these deductions may be applied to all plant tissues, especially as some of the tissues already examined appear to provide exceptions. There is no convincing evidence at present that any plant tissue utilizes the polyphenol system in its normal respiration: the numerous claims made at one time on its behalf rested on evidence that has since proved to be insufficient. The flavoprotein and ascorbic acid systems may, however, operate.

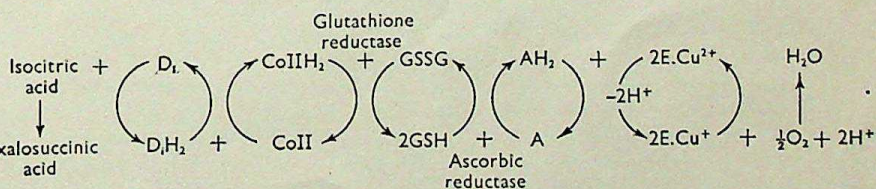
The sterile spadix of some aroid inflorescences is noted for its rapid respiration, leading to the

production of much heat and a rise of temperature around the flowers enclosed in the spathe. This is a very exceptional tissue, and investigation of its respiration has led to unusual results. Its very rapid respiration cannot be inhibited by cyanide, azide, carbon monoxide, or malonic acid, that is to say by any of the inhibitors to which cytochrome oxidase and its associated succinic dehydrogenase are particularly susceptible. No cytochrome oxidase can be extracted by the usual methods, and

the other metallo-enzymes, polyphenol and ascorbic oxidases, seem to be absent also. A crude preparation of an autoxidizable flavoprotein has been obtained [16], though attempts at

purification have not yet succeeded. Since the activity of homogenates is greatly increased by addition of riboflavin, and the respiration of the tissues is markedly sluggish towards oxygen, it is probable that the role of the terminal oxidase is here filled by a non-metallic flavoprotein enzyme.

Numerous experiments carried out at Oxford indicate that the meristems of young barley roots soon fail to produce the cytochrome system found in the embryo. Inhibition by cyanide persists, but all the other criteria of cytochrome oxidase activity disappear after the first few days, and in their place a marked susceptibility to 'dieca' (sodium diethyldithiocarbamate) develops. The known facts are most readily explained on the assumption that the respiratory oxidations are carried through this phase by the ascorbic system. Malic acid can be oxidized by it through coenzyme-I, and recent results [19] indicate that isocitric acid, whose dehydrogenase requires coenzyme-II, may be oxidized by way of glutathione (GSH):



So far, the ascorbic system has not been linked with the oxidation of succinic acid, and it is uncertain whether the entire Krebs cycle of oxidations can be promoted by it. Collateral experiments with wheat and rice indicate a steady adherence to the cytochrome system; the remarkable

oxidase-shunt operated by the young root-tips of barley, while maintaining a uniform rate of respiration, appears to be characteristic of barley itself. The mechanism of respiratory oxidation in mature plant-tissues is still very uncertain.

The oxidations of plant respiration, like those of animal tissues, promote the phosphorylation of adenosine diphosphate (ADP) to adenosine triphosphate (ATP) with a consequent retention of transferable energy. The isolated 'mitochondria' perform this reaction while oxidizing pyruvic acid. It has not yet been possible to determine the full amount of phosphate esterified, because of active hydrolysing enzymes also present. It exceeds, and perhaps greatly exceeds, one phosphate per atom of oxygen consumed, equivalent to twelve or more per hexose molecule, as compared with a net gain of two or three during anaerobiosis. Glycolysis provides enough ATP by the dephosphorylation of 1,3-diphosphoglyceric acid and *enol*phosphopyruvic acid to phosphorylate fresh hexose and maintain the cycle (figure 7). The net gain of ATP that might be applied to other cell requirements is small, and it is notorious that growth and synthesis—indeed, all the most energetic cell activities—come to a stop without oxygen; even mere maintenance of the system becomes precarious before long. When, with the help of the oxidation trains of the cell, oxygen replaces pyruvic acid or acetaldehyde as electron acceptor, the oxidation, instead of reduction, of pyruvic acid and its products greatly increases the amount of ATP formed for a given hexose consumption. The proportion needed to continue the phosphoryla-

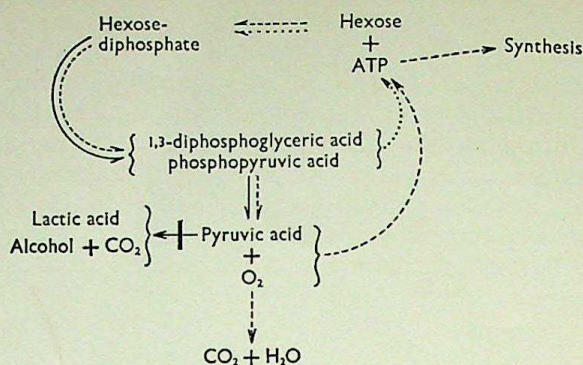


FIGURE 7 - The effect of oxygen in the phosphorylation cycle. Anaerobic processes are shown by solid or dotted lines, aerobic by broken lines. The dotted lines indicate that the process is slower than its aerobic equivalent.

tions of glycolysis becomes less, and the excess ATP is available to promote the many syntheses known to depend upon its energy, including amidations and the peptide linkages that build the primary valency chains of proteins; perhaps, indeed, growth syntheses in general.

Comparing what is known of plant respiration with the corresponding processes in other types of organism, one cannot help being impressed by the fundamental unity of biochemical procedure. Almost without exception carbohydrates are phosphorylated, fructofuranose-1,6-diphosphate is split to pyruvic acid, and pyruvic acid is wholly or partially degraded to carbon dioxide. The first stages may be regarded as an activation and the last as the delivery of energy from the vantage-point thus obtained.

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Book reviews

CLASSIFICATION OF FUNGI

Flore analytique des champignons supérieurs, by R. Kühner and H. Romagnesi. Pp. 556, with 677 text figures. Masson et Cie., Paris. 1953. Paper cover, fcs 7010; bound, fcs 7970 net.

Considering the eminence and international reputation of the authors of this work, it is not surprising that it is difficult to describe its scientific value without resort to superlatives. The taxonomic treatment of some 2500 species and varieties of fungi included under the headings agarics, bolets, and chanterelles is essentially based on many years of personal observation, though the authors have been influenced by the generally accepted views of other mycologists. The text is divided into clearly defined sections, which greatly facilitates specific determination. It is illustrated by numerous small, but delightfully drawn, sketches of fungi or their parts. In addition to the main taxonomic treatment, some fifty pages are devoted to supplementary information on such things as poisonous fungi, investigation technique, and colour concordance. There are a very full glossary and an adequate index.

Some criticism is, however, inevitable. In starting with Fries' *Epicrisis* of 1836 instead of his *Systema* of 1821, the authors show a light-hearted indifference to the rules of international nomenclature; this, however, might be regarded as not so much a matter for criticism as for congratulation. New species, new varieties, and new names appear with startling frequency, but with no Latin diagnosis—not even a description. The manner in which Friesian genera have been shuffled and re-dealt is often bewildering, in spite of the indispensable table of comparison between Friesian classification and the authors' rearrangement. The division of genera into so-called 'natural' groups is often dependent on very detailed microscopic examination, as for instance in the genus *Tricholoma*, where the primary separation into groups is based on such characters as amyloid spores and hyphal clamps.

No criticism, however, could seriously detract from the scientific value of this excellent work. Its great merit is that it does exactly what it sets out to do and does it remarkably well. It is one of the outstanding contributions of modern times towards the solution of

the problems inherent in the taxonomy of the fungi.

W. H. WILKINS

GENETICS

The Facts of Life, by C. D. Darlington. Pp. 467. George Allen and Unwin Limited, London. 1953. 35s. net.

Professor Darlington's book starts with an amusing history of the science of heredity, from the Bible to Darlington, with excursions to telegony, the Kammerer case, and Lysenko. It builds up a *Weltanschauung* explaining the riddles of the universe in terms of chromosomes and genes, and ends with a new gospel designed to cure scientifically the evils of our time. Thus, problems old and new—cancer, evolution, language, criminality, race, the classes in human society, divorce and homosexuality, Freud, the belief in immortality, the rise and fall of civilization, and the indeterminacy principle—are solved by saying that it is all due to the genes. The principle that what is genetically determined is rather a norm of reaction than manifest characters seems to be by-passed in a rather cavalier fashion.

The Bachs, the Bernoullis, and the Darwins 'owed their gifts to heredity' (p. 275). So be it: but Beethoven, son of a notorious drunkard, was highly undesirable by all eugenic standards, and Goethe was the son of the remarkably mediocre Rath of Frankfurt and ancestor of an equally inconspicuous progeny. How, then, is Darlington's remedy for the ailments of our time going to work, to wit, that the State should control fertilization (p. 357)? There are a 'diagram of love' (p. 327) and, somewhat lacking in taste in the context, a table on the fertility of bulls as established by the results of artificial insemination (p. 337). The genetic character expressed by the table (classes from 0 to 3000+ cows fertilized per bull per annum—the human counterpart of the latter, class VIII, 'being responsible for the greatest poetry,' p. 341) 'decides the success or failure of a marriage both from the view of the individuals concerned and of the community' (p. 344). 'We can now understand the modes of action (of genes, chromosomes, plasmagones, and viruses) in heredity and development, in infection and immunity, in the animal body and even in the human

mind' (p. 389). Can we? We know that genes in the mould *Neurospora* interfere in the production of certain enzymes, that certain amino acids are responsible for the eye colour in *Drosophila*, and the like. Who has the faintest idea of how chains of nucleic acids, called genes, are capable of producing even the organization of a fly or a mouse, not to speak of the musical genius in the Bach family or the criminality of the Lange twins? 'The materials of heredity contained in the chromosomes are the solid stuff which ultimately determines the course of history' (p. 404). So simply explained are human affairs!

The impact of genetics on modern science, pure and applied, on medicine and the social sciences, can hardly be over-estimated. It seems doubtful, however, whether over-simplifications and half-truths will do much service for its popularization. Professor Darlington is, however, highly successful in giving us a mythology of the gene, where those little nucleic acid dots play a role similar to that of fairies, furies, and gods in the times of old.

LUDWIG VON BERTALANFFY

FOAMS

Foams: Theory and Industrial Applications, by J. J. Bikerman, with chapters by J. M. Perri, R. B. Booth and C. G. Currie. Pp. 347, with half-tone and line illustrations. Reinhold Publishing Corporation, New York. 1953. 80s. net.

This book is a unique compilation of information of all kinds on foams, and as such should be valuable to a wide circle of readers, particularly to industrialists whose processes either depend upon foams or are troubled with unwanted foams. There are chapters on the structure of foams, their mechanical, electrical, and optical properties, their rate of drainage, and the use of foams for separating constituents of solutions; also accounts of foams suitable for fire-fighting and methods of testing their efficacy, of the froth-flotation process for mineral separation, and of substances with foam-destroying properties. There are copious references to original papers and patents—indeed, some parts of the book are mainly a survey of patent literature. Although there is a good deal of theory scattered throughout the

book, it is neither well co-ordinated nor original, and the chapter on the theory of foams is so badly out of date that it ignores most of the work done on the structure of surface films on water or aqueous solutions since 1900. As a compendium of useful information, this book has considerable value; as a contribution to the difficult science of foaming it is of minor importance.

N. K. ADAM

INVERTEBRATE PALAEOLOGY

Traité de Paléontologie, publié sous la direction de Jean Piveteau. Volume III. Les formes ultimes d'invertébrés: morphologie et évolution. Onychophores—Arthropodes—Echinodermes—Stomocordes. Pp. viii + 1063, with 1274 figures and 17 plates. Masson et Cie., Paris. 1953. Paper covers, fcs 9600; bound, fcs 10 320 net.

Sixty-one years ago K. A. v. Zittel completed his famous 'Treatise on Palaeontology' (*Handbuch der Paläontologie*), which represented his life's work. Some time ago Professor Jean Piveteau of the Sorbonne undertook the publication of a *Traité de Paléontologie* in seven volumes, and, within a year after the publication of the first two volumes, the third volume is now ready. It deals with highly organized invertebrates. The years that have passed since the publication of Zittel's work have brought a considerable widening of relevant knowledge and a deeper insight into the natural inter-relationships of the organisms. This is particularly noticeable in this third volume. One of the most striking changes in the system of classification concerns the position of the now extinct Graptolites. Originally considered to be plants, and classified by Zittel among the Hydrozoa, they have now been recognized as relations of the Pterobranchia, and thus belong to the Stomochordates, occupying a position intermediate between the Echinodermata and the Chordata.

Zittel's treatise was entirely his own work and as such of a strikingly uniform character. A command of the whole field of palaeontology is today beyond the capacity of one worker. The editor therefore secured the co-operation of a number of French palaeontologists, to whom he allocated the various sections. The contributors to the third volume are: F. M. Bergounioux, L. Cuénot, C. Dechaseau, M. Deflandre-Rigaud, N. Grekoff, P. Hupe, D. Laurentiaux, J. Piveteau, J. Roger, H. and G. Termier, G. Ubachs, and G. Waterlot.

They were apparently given complete freedom in the execution of their task, and thus a symposium of great variety has resulted. Illustrations are plentiful and of excellent quality throughout.

Emphasis lies on zoology; stratigraphy seems to have been neglected on occasions. Systematics mostly goes as far as the genera. The bibliography is valuable, though by no means complete. The work will be an indispensable aid to palaeontological research.

EMIL KUHN-SCHNYDER

DICTIONARY OF ENGINEERING

Dizionario d'Ingegneria, edited by Eligio Perucca. Volume III, FOS-MOS. Pp. viii + 1043, with 2100 figures and four plates. Unione Tipografico-Editrice Torinese, Turin. 1953. Lire 12 000.

This volume must have been awaited with impatience by everybody, in Italy or elsewhere, who has had the opportunity of consulting its two predecessors, reviewed in the April 1953 issue of ENDEAVOUR. This dictionary is a veritable mine of up-to-date information and a collection of little monographs written by experts, some of which will be read with profit not only by engineers; one would like to mention in particular that on measurement and systems of units. Cross-indexing is one of the most successful features, and makes it possible readily to extract the desired information, even if one has not been wise or lucky enough to guess directly the entry containing it.

Of course, different readers, with different biases, will find that not enough has been said about their pet subjects—for instance, in the case of the reviewer, photoconductivity. Also the standard of knowledge required from the user does not appear to be completely uniform. Few references are given, and it is felt that more help should have been provided for those requiring more detailed information. A feature very helpful to non-Italian readers would have been the universal decimal classification of the various entries—but this would have been a major undertaking in itself.

The illustrations are excellent, and the production generally is very good; hardly a misprint has been noticed. This work will become the authority on Italian technical terms in the field of engineering, and the editor is to be congratulated again for this most unselfish labour so brilliantly carried out.

L. PINCHERLE

CHROMATOGRAPHY

Chromatography: a review of principles and applications, by E. Lederer and M. Lederer. Pp. xviii + 460. Elsevier Publishing Company, Amsterdam. 1953. 60s.net.

This work, a revised edition of two monographs previously published in French, is a useful addition to the literature of chromatography. It represents the first attempt—and a successful one—at a comprehensive review of the method as a whole since it has become widely used. It has two defects inherent in any undertaking of this kind. The first is that the choice of literature references is subjective; although some two thousand publications are cited, these represent only a fraction of the total. To make a universally acceptable choice is impossible, but nevertheless the authors offer the reviewer little scope for serious criticism; the only point to which it is, perhaps, worth while to draw attention in this connection is that there is no mention of the paper chromatographic work of Liesegang, which deserves to be better known than it is. The second inherent defect is that, like all textbooks dealing with a rapidly developing subject, it became out of date even while it was in the press. It is therefore to be hoped that having put all chemists greatly in their debt by successfully distilling the essence of chromatography the authors will continue the process by offering successive editions at not too long intervals.

A minor point of criticism, which, however, in no way detracts from the practical value of the book, is the reiteration of the statement that Tswett was the originator of chromatography. While none would seek to belittle Tswett, who did outstanding work and may have been an independent discoverer of adsorption column chromatography, the perpetuation of this story does a great injustice to the memories of such earlier pioneers in the same field as Matteucci, Goppelsroeder, Thomson, Way, Reed, Nasse, Engler, Boehm and, above all, the American petroleum chemist D. T. Day.

The preparation of such a valuable work of reference must have been a very great labour, but labour well repaid by its usefulness. The book is concisely written and contains an immense fund of information on all branches of chromatography; must be looked upon as the standard work on the subject. It can be strongly recommended and should be possessed by, or readily available to, all chemists.

T. I. WILLIAMS

THOMAS YOUNG

Thomas Young, *Natural Philosopher, 1773-1829, a biography by the late Alex Wood, completed by Frank Oldham. Pp. xx + 355. Cambridge University Press, London. 1954. 30s. net.*

This handsome volume is a worthy tribute to one of the greatest of British natural philosophers. A native of Milverton in Somerset, Thomas Young very early gave signs of exceptional intellectual powers; he could read with considerable fluency at two years of age, and before he was four he had read the whole Bible through twice. The precocity was not sterile and fleeting, but developed into a steady capacity for the rapid assimilation of knowledge, which, backed by a typically Quaker habit of industry, soon made Young one of the most learned men of his time. His interests were remarkably wide, and the range and depth of his original investigations have not often been paralleled. He shared with Champollion—whom he quite probably anticipated—the honour of having been the first to decipher Egyptian hieroglyphics; he suggested the wave theory of light; he effectively established the science of physiological optics; he was an accomplished philologist; and he was superintendent of the 'Nautical Almanac' and secretary of the Board of Longitude. This does not by any means exhaust the list of his achievements, but it serves to illuminate the versatility of his genius.

The late Alex Wood collected material for this biography over more than forty years, in the scanty leisure allowed him by his social work and by his duties as Tutor of Emmanuel College, Cambridge, and university lecturer in physics. It is a model of what a biography should be; unfortunately Wood did not live to finish it, but the task has been very well completed by Mr Oldham. The book is excellently produced and illustrated, and is enriched by a memoir of the author by Canon C. E. Raven; this last feature will be particularly welcome to those Cambridge men who profited not only from Alex Wood's inspired teaching but from his warm personality.

E. J. HOLMYARD

RECENT ORGANIC CHEMISTRY

Progress in Organic Chemistry, Vol. 2, edited by J. W. Cook. Pp. 212. Butterworths Scientific Publications, London. 1953. 42s. net.

The six chapters in this book are all written by authors who are actively

contributing to the rapid progress now taking place in certain sections of organic chemistry. These concise reviews will be of the utmost value to all whose research work bears any relation to the subjects under discussion. Those whose interest is of a more general nature will be stimulated to consult the original papers, to which numerous references are provided.

With a few exceptions in one chapter the literary style is particularly good, misprints are almost absent, and the infectious enthusiasm of the authors is clearly revealed. This has led in one section to the somewhat excessive, though understandable, use of such terms as admirable, brilliant, elegant, and excellent in describing various researches.

The first impression, that possibly too much space is allotted to the three closely related themes, triterpenes, cortisone, and carcinogenic hydrocarbons, is entirely dispelled by the interesting treatment, and the decision to include these subjects is amply justified.

Even the non-specialist must be continually delighted by the impact of theory on experiment and by the application of unusual reagents or reactions and of modern physical methods. A few instances may be cited—the microbiological hydroxylation of steroids on the important carbon atom 11, and the use of -6:6'-dinitrodiphenic acid for the resolution of ($\pm$) anabasine, of bismuth oxide for the oxidation of acyloins, and of oxygen adsorbed on active charcoal in the study of pyridoxamine. In conclusion we may mention that, like Volume I, this production is a happy instance of international co-operation.

FREDERICK CHALLENGER

CONTINENTAL CLIMATES

The Climates of the Continents, by W. G. Kendrew. Fourth edition. Pp. 607. Oxford University Press, London. 1953. 50s. net.

When this book was first published in 1922 it almost at once became a standard work, and from that time to the present it has remained the first book in the field to be consulted by student and teacher alike. The title aptly describes the contents: the two introductory chapters, dealing generally with climatic data and world pressure and wind systems, occupy only fifteen pages. Chapter III plunges straight into the climate of Africa, taking first

the continent as a whole and then the main countries or regions. The same sequence is followed with each continent in turn, with half a dozen pages of temperature and precipitation statistics at the end of each continental section.

The third edition appeared in 1937 and had been reprinted thrice before the appearance of this fourth edition. The present edition is almost a new work: it has been revised throughout, greatly enlarged, and entirely reset. The general climatic features have been restated in terms of modern air-mass meteorology and fronts. Though the tables suggest an undue emphasis on average monthly temperatures and rainfall, this is counteracted by the many vivid little descriptions of local weather and climate in the text—often culled from the reports of observant non-scientific residents. The continent of Antarctica now has a chapter to itself, but not the Arctic, which is not a continent. The selection of regions remains unsystematic, dictated by availability of material or the author's own interests. Thus North America is treated as a whole, followed by a chapter on the climatic regions of Canada and one on California. It remains a good book with a long life of continued usefulness ahead.

L. DUDLEY STAMP

COLLAGEN

Nature and Structure of Collagen, edited by J. T. Randall, assisted by Sylvia Fitton Jackson. Pp. ix + 269. Butterworths Scientific Publications, London. 1953. 42s. net.

This volume is the published version of papers given at a two-day meeting convened by the colloid and biophysics committee of the Faraday Society at King's College, London, in March 1953—actually twenty-five papers leavened by nine suitably spaced discussions, and finally rounded off with an excellent twelve-page bibliography. The result matches collagen itself in showing marked variations—some papers and discussions are good, while others are not so good—but that is only to be expected in a conference of this sort, especially on a topic of such complexity. Perhaps it would be fair to say that not a high proportion of the material presented is altogether new in the eyes of the protein addict, but for those who are entering the field or who would like to see how things are going, this book can certainly be recommended. Almost

every side of the collagen problem is dealt with to some extent, from orthodox histology to molecular configuration, as well as by techniques up to the very latest. It is a friendly book, too—an important asset with a subject that is everybody's business; for the collagen group rests on a master plan that accounts for nominally half the fibrous proteins. And particularly we in Britain should constantly bear in mind that collagen is not merely the stuff of the leather industries: it is also, and much more emphatically, the raw material of that great composite human burden, the so-called rheumatic diseases.

W. T. ASTBURY

GUIDE TO THE MOON

Guide to the Moon, by Patrick Moore. Pp. 224, with 12 plates, 13 figures, and map. Eyre and Spottiswoode Limited, London. 1953. 16s. net.

The Moon is our nearest neighbour in space, and much detail can be seen on its surface with even a small telescope. Its observation is consequently much favoured by amateur observers possessing telescopes of moderate size, who have contributed greatly to the detailed knowledge of lunar topography.

Mr Moore, who is an assiduous lunar observer, has summarized in this book the historical progress of our knowledge of the Moon and its present state. The book will be particularly useful to owners of small telescopes who wish to study the Moon in greater detail. The observation of the detailed topographical structure is complicated by the changing appearance with changing conditions of illumination as the phase and librations of the Moon change. I feel that considerable caution is needed in accepting reports of changes in appearance, and also of long-continued obscuration of features by mists. Though it is not impossible that the Moon may have an extremely thin atmosphere of heavy gases, there is no conclusive proof that it has; Mr Moore has been too ready, in my opinion, to assume the existence of an atmosphere. The evidence for the meteoritic origin of the ring craters has been much strengthened in recent years. Mr Moore discards this theory without adequate discussion and puts forward a highly improbable theory, which does not adequately account for the bright rays.

The later chapters of the book deal with the question of the possibility of

life on the Moon and the problems of space travel to the Moon. There are several useful appendices, including a description of the principal lunar features.

H. SPENCER JONES

LIFE OF CARDAN

Cardano, the Gambling Scholar, by Oystein Ore; with a translation from the Latin of Cardano's Liber de Ludo Aleae, by S. H. Gould. Pp. xiv + 249. Princeton University Press, Princeton; Geoffrey Cumberlege, London. 1953. 25s. net.

As a physician, Cardan established a European reputation comparable with that of Vesalius. As a mathematician, too, he was among the most eminent of the sixteenth century, and his *Ars Magna* is regarded by many as the first mathematical work to go decisively beyond the limits established by the Greeks. Although the present work contains much information, very readably presented, about Cardan's life generally, and his somewhat questionable dealings with his fellow mathematicians, its principal interest lies in its account of his application of mathematics to the even then widely prevalent vice of gambling. The last quarter of the book is a translation of his *Liber de Ludo Aleae*, which contains the first serious study of the theory of probability. From it, modern gamblers too might learn; at the same time, they would do well to ponder the fact that much of Cardan's life was spent in wretchedness and poverty.

Among the four plates which illustrate this work is the well known 'Card Players,' which Professor Oystein Ore, in common with others, looks upon as being probably the work of Zuccaro. It is likely, however, that this is in fact one of four identical pictures—one for each of the card players portrayed—all of which may still exist, painted by John Bettes (c.1520-80).

T. I. WILLIAMS

NUCLEAR PHYSICS

Nuclear Physics, by W. Heisenberg. Pp. 224. Methuen and Company Limited, London. 1953. 12s. 6d. net.

This is an English translation of a series of lectures revised in 1948, intended, in the author's words, 'for readers who, while interested in natural sciences have no previous training in theoretical physics and yet are familiar to a certain extent with physical ideas.'

It does indeed start right from the beginning, dealing with atoms and

molecules, as well as electrons, protons, and neutrons. Classical radioactivity is well described, and there is a good and thorough account of the relation between the mass or the binding energy of a nucleus and the numbers of protons and neutrons which it contains. Considering that no mathematics are used, a remarkably clear statement is given of the main features of the forces that hold nuclei together, and of some theories which try to explain them. On the other hand, more might perhaps have been made of energy levels. The chapter on experimental methods, though too short to give more than the barest outline, should help to make the theory more real. There is a good account of applications up to the date of the revision of the text, and a reprint of Heisenberg's article in 'Nature' in 1947 describing the German atomic energy work during the war. In most respects this book can be recommended as very well suited to the class of reader for whom it is intended, and, as might be expected from its author, it contains much to stimulate thought in those whose knowledge of the subject goes a good deal farther.

I must, however, object to some points in the historical survey. The Epicureans, as exemplified by Lucretius, did not regard the world as determinist. On the contrary, they introduced a curious kind of arbitrary deviation of the moving atoms, which Lucretius (II, 292) called *clinamen*, and which anticipated in a most remarkable way Heisenberg's own 'uncertainties,' for the precise purpose of breaking the causal sequence 'lest cause follow cause for ever.' Lucretius even went so far as to use this hypothesis to explain free will:

*Unde est haec inquam fatis avolsa
polestas
per quam progredimur quo ducit
quemque voluntas.*

—Luc. II, 258

'From this I say we snatch
from fate the power,
That each may walk where
his own will may lead.'

Finally, why cite Hittorf as the discoverer of the charge-mass ratio of cathode rays? Whatever preliminary work he may have done, it was not comparable with the classical experiments of J. J. Thomson or those of Weichert or of Kaufmann.

G. P. THOMSON

Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Insecticides and Colonial Agricultural Development, edited by T. Wallace and J. T. Martin. *Proceedings of the Sixth Symposium of the Colston Research Society*, 1953. Pp. 169. Butterworths Scientific Publications, London. 1954. 30s. net.

Soil, by G. V. Jacks. Pp. 221. Thomas Nelson and Sons Limited, London. 1954. 12s. 6d. net.

ASTRONOMY

Nébuleuses Galactiques et Matière Interstellaire, by J. Dufay. Pp. 492. Editions Albin Michel, Paris. 1954. Fcs 1650 net.

BIOCHEMISTRY

Biochemical Preparations, Vol. 3. Editor-in-chief E. E. Snell. Pp. 128. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1953. 28s. net.

The Biochemistry of Genetics, by J. B. S. Haldane. Pp. 144. George Allen and Unwin Limited, London. 1954. 15s. net.

Convegno sulle Vitamine—Milano, 1953. Pp. lix + 883 + xxvii. Consiglio Nazionale delle Ricerche, Rome. 1953. Lire 4000.

Mécanismes Biochimiques de l'Activité des Antibiotiques, by M.-M. Janot and J. Keufer. Pp. 74. Masson et Cie., Paris. 1954. Fcs 670 net.

Principles of Biochemistry: A Biological Approach, by M. V. Tracey. Pp. 194. Sir Isaac Pitman and Sons Limited, London. 1954. 20s. net.

BIOLOGY

Evolution as a Process, edited by Julian Huxley, A. C. Hardy, and E. B. Ford. Pp. 367. George Allen and Unwin Limited, London. 1954. 25s. net.

Mammalian Hybrids, by Annie P. Gray. Pp. 144. Commonwealth Agricultural Bureaux, Farnham Royal, Bucks. 1954. 21s. net.

Synthetische Artbildung, by H. Nilsson. Pp. 1303. C. W. K. Gleerup, Lund. 1953. Two volumes. Paper covers, Skr. 225; bound, Skr. 250 net.

Viruses. Cold Spring Harbor Symposia on Quantitative Biology, Vol. XVIII. Pp. 301 + xvi. The Biological Laboratory, Cold Spring Harbor, New York. 1954. \$8 net.

BOTANY

Bibliographie der Pflanzenschutz-Literatur, Volumes I and II, 1940-45, by J. Bärner. Pp. 1308. Verlag Paul Parey, Berlin. 1953. D.M. 97.

Growth and Differentiation in Plants, edited by W. E. Loomis. Pp. 458. The Iowa State College Press, Iowa. 1953. 56s. 6d. net.

New Concepts in Flowering-plant Taxonomy, by J. Heslop-Harrison. Pp. 135. William Heinemann Limited, London. 1953. 6s. net.

Plants for Man, by R. W. Schery. Pp. 564. George Allen and Unwin Limited, London. 1954. 70s. net.

CHEMISTRY

Chemical Nomenclature; Symposium on Chemical Nomenclature, September 1951. Pp. 112. American Chemical Society, Washington, D.C. 1953. \$2.50 net.

Chemistry of the Defect Solid State, by A. L. G. Rees. Pp. 136. Methuen and Company Limited, London; John Wiley and Sons Inc., New York. 1954. 8s. 6d. net.

The Chemistry of the Morphine Alkaloids, by K. W. Bentley. Pp. 433. Oxford University Press, London. 1954. 50s. net.

Experimental Inorganic Chemistry, by W. G. Palmer. Pp. 577. Cambridge University Press, London. 1954. 50s. net.

Hydrocarbons from Petroleum, by F. D. Rossini, B. J. Mair, and A. J. Streiff. Pp. 556. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1954. 148s. net.

A New Periodic Table of the Elements, by S. I. Tomkeiff. Pp. 30. Chapman and Hall Limited, London. 1954. 10s. net.

GENERAL

Conversation with the Earth, by H. Cloos (translated from the German by E. B. Gartside). Pp. 427. Routledge and Kegan Paul Limited, London. 1954. 30s. net.

Elektrische Triebfahrzeuge, Vol. I and II, by Karl Sachs. Pp. xv + 700, and xii + 696 respectively. Verlag Huber und Co. A.G., Frauenfeld. 1953. Swiss fcs 65 each volume.

Let There Be Bread, by Robert Brittain. Pp. 263. Spalding and Levy Limited, London. 1953. 12s. 6d. net.

Petrography. An Introduction to the Study of Rocks in Thin Sections. Pp. x + 406. W. H. Freeman and Company, San Francisco; Bailey Bros. and Swinfen Limited, London. 1954. 56s. net.

Rocks and Mineral Deposits, by P. Niggli (English translation by R. L. Parker). Pp. xiii + 559. W. H. Freeman and

Company, San Francisco; Bailey Bros. and Swinfen Limited, London. 1954. 102s. net.

HISTORY OF SCIENCE

Great Discoveries by Young Chemists, by J. Kendall. Pp. 231. Thomas Nelson and Sons Limited, London. 1953. 12s. 6d. net.

Nature and the Greeks, by E. Schrödinger. Pp. 97. Cambridge University Press, London. 1954. 10s. 6d. net.

PHYSICS

Acoustics, by T. M. Yarwood. Pp. 346. Macmillan and Company Limited, London. 1953. 15s. net.

Analysis of Deformation, Vol. I: Mathematical Theory, by K. Swainger. Pp. 285. Chapman and Hall Limited, London. 1954. 63s. net.

Annual Review of Nuclear Science, Vol. 3, 1953. Pp. 412. Annual Reviews Inc., Stanford, California. 1953. \$7 net.

Discontinuous Automatic Control, by I. Flügge-Lotz. Pp. 168. Princeton University Press, Princeton; Geoffrey Cumberlege, London. 1954. 32s. 6d. net.

Elementary Introduction to Molecular Spectra, by B. Bak. Pp. 125. North Holland Publishing Company, Amsterdam. 1954. Fl. 9 net.

Nuclear Moments, by N. F. Ramsey. Pp. 169. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1954. 40s. net.

Report on the Atom, by G. Dean. Pp. 288. Eyre and Spottiswoode Limited, London. 1954. 16s. net.

The Revolution in Physics, by L. de Broglie. Pp. 310. Routledge and Kegan Paul Limited, London. 1954. 18s. net.

TECHNOLOGY

British Plastics Year Book 1954. Pp. 600. Iliffe and Sons Limited, London. 1954. 30s. net.

Forest Products Research and Industries in the United States, by W. W. Varossieau. Pp. xii + 796. J. M. Meulenhoff, Amsterdam. 1954. Fl. 45 net.

Oil in the Soviet Union, by H. Hassmann (translated by Alfred M. Leeston). Pp. 173. Princeton University Press, Princeton; Geoffrey Cumberlege, London. 1954. 30s. net.

The Structure of Textile Fibres. An Introductory Study. Pp. 165. The Textile Institute, Manchester. 1953. 12s. 6d. net.

E. N. DA C. ANDRADE,
D.Sc., Ph.D., LL.D., F.R.S.,

Was born in London in 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914-18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain Professor of Physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state, which he built up again after his laboratories had been completely destroyed by bombs in September 1940. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He has a well known collection of early books on the exact sciences, and is an authority on Newton and his contemporaries. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences*. He is known for the clarity of his exposition of science, both in writing and by lectures.

D. A. WITTOP KONING,
B.Ph., Dr. Sc.,

Was born in 1911, and studied pharmacy at the Municipal University of Amsterdam, where he has given lectures on the history of pharmacy since 1948. He is Curator of the Historical Medical-Pharmaceutical Museum of Amsterdam, and Treasurer of the *Union d'Histoire des Sciences*. His historical publications include books on Dutch mortars (*Nederlandse Vijzels*, Deventer, 1953), 'Art and Pharmacy' (Deventer, 1950), and Dutch weights. His book on Delft pharmacy pots (*Delftse apothekerspotten*, Deventer, 1954) is now in the press.

ADRIEN JAQUEROD,
Dr. Sc.,

Was born at Geneva in 1877, and in 1905 became Professor of Physics and Pure Mechanics in the University of Neuchâtel, where he is now Honorary Professor. He has published papers on gases (thermometry, molecular weight), deviations from Hooke's law, chronometry, and such properties of glasses as relate to isochronous oscillations. In 1920 he set up the *Laboratoire Suisse de Recherches Horlogères*, which he directed until 1950.

F. I. G. RAWLINS,
M.Sc., F.R.S.E., F.S.A., F.Inst.P.

Born in London, 1895; educated at the Universities of Edinburgh, Cambridge, and Marburg. Scientific adviser to the National Gallery since 1934: a deputy-keeper since 1948. Author of numerous papers in 'Technical Studies in the Field of the Fine Arts,' and other journals, dealing with the use of scientific methods in relation to paintings. Since 1951, vice-president and secretary-general of the International Institute for the Conservation of Museum Objects, and editor of 'Studies in Conservation.'

A. E. A. WERNER,
M.A., M.Sc., D.Phil.,

Was born in Dublin in 1911. He studied at Trinity College, Dublin, and at the University of Freiburg im Breisgau under Professor H. Staudinger. After graduating he was appointed lecturer, and later reader, in chemistry at Dublin University, where he carried out research on the chemistry of the ureides. Since 1948 he has been engaged as research chemist at the National Gallery, London.

SIR RUDOLPH PETERS,
M.C. (with bar), M.D., D.Sc., F.R.C.P., F.R.S.,

Was born in London in 1889 and has been Professor of Biochemistry in the University of Oxford since 1923, and Fellow of Trinity College, Oxford. He holds honorary degrees of the Univer-

sities of Paris, Liège, Amsterdam, and Cincinnati. He is an Hon. Fellow of Gonville and Caius College, Cambridge, and foreign member of several academies. He was educated at Wellington College, King's College (London), Cambridge University, and St. Bartholomew's Hospital (London). As Dunn lecturer in biochemistry at Cambridge he turned his attention to vitamin problems and later pursued them more intensively in Oxford. In 1930 came the first demonstration of the *in vitro* action of a vitamin, shown by the specific response of B₁ avitaminous pigeon's brain tissue to vitamin B₁ (thiamine). This led to the proof of the intimate connection of this vitamin with the metabolism of pyruvic acid, and to investigations on 'biochemical lesions.' Together with earlier work on arsenical compounds, a test system was provided which formed a basis for work in Oxford during the second world war, leading to the development of British anti-lewisite. As chairman of the Accessory Food Factors Committee, he took part in nutritional work during the war, and acted as chairman of the Vitamin C sub-committee concerned with the Vitamin C trials at Sheffield.

W. O. JAMES,
M.A., D.Phil., F.R.S.,

Was born in London in 1900 and was educated at Tottenham Grammar School and the Universities of Reading and Cambridge. Worked first on the potassium nutrition of plants on field plots at Rothamsted. Reader in botany in the University of Oxford, and since 1927 has led a school of teaching and research in plant physiology, especially concerned with nutrition and respiration. Director of the Oxford Medicinal Plants Scheme during the war and after, dealing with the production of drug plants in Britain and with the study of alkaloid metabolism in the Solanaceae. An editor of the 'New Phytologist.' Has published 'The Biology of Flowers' (with A. R. Clapham), 'Plant Respiration,' some well known text-books, and numerous papers in several branches of botany.

ENDEAVOUR

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of mankind

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Sir Charles Parsons (1854-1931)

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The remarkable career of Charles Parsons strikingly demonstrates that the development of the individual can be profoundly influenced by both heredity and environment, however fiercely the relative importance of these two factors may be argued. None can doubt that his inventive genius was inherited from his unusually gifted parents or that its practical application—which found its fullest, though by no means only, application in the development of the steam turbine—owed much to the circumstance that his nursery was a well equipped workshop and his childhood toys were engineers' tools. While the steam turbine might have been invented without Parsons—for its principle was not new and the needs of the rapidly growing electrical industry gave inventors of his day a powerful incentive to develop a high-speed steam engine free from reciprocating action—it was surely this exceptional combination of circumstances which resulted in one man making so overwhelming a contribution to one of the greatest of engineering inventions.

Parsons, born on 13th June 1854, was the youngest of the six sons of the third Earl of Rosse, who was an astronomer of high distinction, for six years President of the Royal Society. The six-foot mirror for his great reflecting telescope was cast and polished in his own workshops at the family seat, Birr Castle, Parsonstown, Ireland. For many years this instrument had no rival, and it attracted to the Earl's household many eminent mathematicians and astronomers, some of whom acted as tutor to the family.

When not with his tutors, Charles was constantly with his father in the castle workshops, foundries, and chemical laboratory, and showed great aptitude for doing things with his hands. Even as a boy he was an excellent mechanic, though his ambitious experiments sometimes led him into trouble. Once he ran home with a steel splinter hanging from one eye, the result of the bursting of an air-gun he had made; on another occasion an explosion of gunpowder blew off his eyebrows. He had unusual opportunities for learning seamanship, knowledge of which stood him in good stead later, as the family holidays were spent on their large yacht, the *Titania*.

His father's death in 1867 left him wholly in his mother's care, but happily for his budding genius she was cast in almost as unusual a mould as was his father. She, too, was excellent at every handi-

craft and played her part in the workshops. She was a skilled modeller and became an expert photographer—having a room specially fitted up for the purpose—in the early days of the art.

At seventeen Parsons was sent to read mathematics at Trinity College, Dublin, where his father had been Chancellor, and a year later went to St John's College, Cambridge. In 1877 he passed out as Eleventh Wrangler. It is interesting to note, however, that in his engineering career formal calculation interested him little, and he generally reached his results almost instinctively, by some obscure mental processes which even he himself did not properly understand.

From Cambridge, Parsons went for three or four years as pupil-apprentice at the Armstrong Works, Elswick, and there he translated into practice an epicycloidal engine which had interested him at Cambridge. This engine produced a high rotary speed with little reciprocating action, and may be looked upon as the precursor of his turbine.

In 1881 Parsons went to Kitson's in Leeds, and there continued work on rocket-driven torpedoes which he had begun at Elswick. He was looked upon as socially extraordinary and weird but clearly a great genius. Here an important event took place—he met Katharine Bethell, whom he married early in 1883. His wife shared his anxieties and triumphs, and gave him much support; it is clear, however, that his extreme concentration on his work must often have demanded great understanding on her part.

In 1884 Parsons heard of a good opening with Clarke, Chapman and Company of Gateshead, and he joined them as junior partner. The firm was much interested in electric lighting, which at that time was exciting much attention. To indicate the background to this work it may be recalled that in 1879-80 Edison and Swan were separately working on the incandescent filament, and a year later Sir William Thomson lit his home with Swan's lamps. There was then no public electric supply, but innumerable electric supply companies were being formed to exploit the newly invented dynamo. Parsons appreciated that one of the most urgent engineering needs of the day was for an engine which could drive dynamos directly. Since a high armature speed was desirable, reciprocating action, with its inherent limitations, had to be avoided. In these circumstances the rocket experiments at Gateshead were

put on one side and dynamo and steam turbine experiments were started.

Parsons' first steam turbine patents—his patents eventually numbered more than three hundred in all—were taken out on 23rd April 1884. Unlike earlier inventors who had experimented with turbines, he appreciated that the drop in pressure must be divided into separate steps, each of such a size that the vanes can absorb almost all the available energy of the steam. All large modern turbines incorporate this basic conception. His first compound steam turbine was built in 1884. It developed about ten horse-power and had a speed of about 18 000 revolutions per minute. Later, Parsons introduced important modifications in design, notably the use of a condenser to utilize the low-pressure steam which was at first allowed to go to waste, and of superheated steam at high pressures.

Parsons remained with Clarke, Chapman and Company until 1888, when, anxious to carry out more elaborate and expensive experiments than this firm was prepared to undertake, he set up his own works at Heaton, Newcastle-upon-Tyne. A few trusting friends helped him financially and, after some years of difficulty and anxiety, found their faith and judgment amply justified. Among the difficulties was the fact that the early patents belonged to Clarke, Chapman and Company, so that new developments were restricted. In particular, he was driven to use radial flow of steam, but in 1894 he recovered the patents by agreement and reverted to axial flow, now general practice.

By this time the tide had turned and the inventor began to enjoy the fruits of his labours. The rapidly growing electrical industry, both in Britain and abroad, placed orders for turbines of steadily increasing size. The establishment of his business on a firm footing left Parsons free to develop his ideas in other fields, notably in ship propulsion. In 1894 he fitted up his famous experimental vessel, the *Turbinia*, with which, after initial difficulties, highly satisfactory trials were carried out in 1897. The vessel caused a sensation at the naval review in the Solent which marked Queen Victoria's diamond jubilee in that year. Among the early difficulties may be mentioned that arising from the phenomenon of cavitation, which became marked at the propeller speeds, much higher than any previously experienced, which the direct coupling of turbine and propeller necessitated; this difficulty was largely overcome by modification in propeller design.

The British Admiralty early displayed an in-

terest in Parsons' ship turbines and after installing satisfactory units in smaller vessels used them, in 1906, in the famous *Dreadnought*. Their use thereafter became common practice in the British Navy, and the navies of the world followed this lead. The first merchant ship to be turbine-driven, in 1901, was the Clyde steamer *King Edward*. Cross-channel boats, Atlantic liners, and finally the great Cunarders *Lusitania* and *Mauretania* followed.

The direct coupling of turbine and propeller was inefficient, and adopted only because of the difficulty of transmitting thousands of horse-power through trains of gears, but Parsons realized that reduction gearing—the turbine running fast and the propeller slow—would offer notable advantages; thus slow craft as well as fast could use turbines. He initiated experiments on these lines in 1909 and soon perfected suitable gearing; this entailed cutting the teeth of the gears with exceptional accuracy and using special steels.

Parsons thus lived to see the steam turbine generally adopted both for the generation of electricity from fuel and for the propulsion of the world's naval and merchant fleets. Despite the immense exertions which these achievements entailed, he found time to develop many other interests. Doubtless as a result of his familiarity with the great telescope at his old home, he set up at the Heaton works a unit for manufacturing large parabolic glass reflectors for searchlights; later he took a keen interest in optical glass and in lenses. He acquired a controlling interest in the firm of Ross Limited and also bought up the Derby Crown Glass Works, forming the Parsons Optical Glass Company. He acquired the firm of astronomical instrument makers, Sir Howard Grubb and Company, and transferred the works from St Albans to Heaton, under the name of Sir Howard Grubb, Parsons and Company. This firm has made several very large telescopes, including reflectors of 75-inches aperture for the Radcliffe Observatory, Pretoria, and for the Commonwealth Observatory, Mount Stromlo, Canberra.

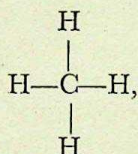
Finally mention must be made of his experiments on the making of diamonds from other forms of carbon. These experiments arose from some he carried out in the 1880s, with the object of making forms of carbon suitable for lamp filaments. He contrived many ingenious methods of subjecting carbon to exceedingly high temperatures and pressures, but although he obtained a few tiny crystals which at first seemed to be diamonds he ultimately reached the conclusion that he could not fully substantiate this claim and so withdrew it.

Some intramolecular electrical effects on the course of chemical change

SIR ROBERT ROBINSON

The electronic theory of organic chemistry, which has so profoundly influenced the development of the subject in the last thirty years, was propounded by Arthur Lapworth and Robert Robinson, who worked independently, but in close consultation, at Manchester University in the third decade of the century. While the author has deprecated the present article as being 'the mixture as before,' it can at least be said that the mixture has proved to possess good tonic properties in the past, and it is probable that it will be as useful in the future.

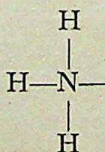
An electronic theory of valency was an almost inevitable consequence of the discoveries of Thomson and of Rutherford, and readers will be familiar with the general idea that the chemist's links between the atoms in a molecule are in fact electrons. Kekulé wrote methane, CH_4 , as



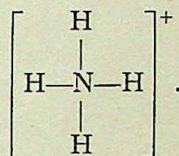
meaning that the quadrivalent carbon atom is bound to a hydrogen atom by each of its four units of chemical affinity. We can use the same symbol as Kekulé, but now each line, representing a valency bond, indicates two electrons shared between the carbon and each of the hydrogen atoms. Obviously H no longer represents a complete hydrogen atom but is really H^+ , a proton, or a hydrogen atom which has lost its one electron.

Although the interpretation in terms of modern wave mechanics is vastly different, we can still usefully employ the old duplet and octet theories of stable electronic configurations, and it is usual to ignore the helium duplet and to say that carbon has four valency electrons. These, together with four from the hydrogen atoms, are all represented in the above formula for methane.

On the same reckoning, nitrogen has five valency electrons, and it is at once obvious why the simplest hydride of nitrogen is ammonia, NH_3 . The nitrogen atom, with five electrons, can take only three more to form the octet, and the symbol is

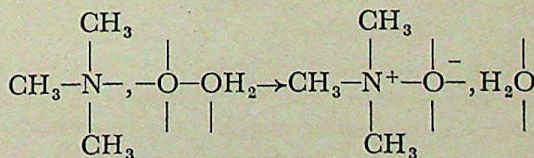


Here the free line represents something that had no place in Kekulé's system. It is what the Americans called 'a lone pair,' two electrons in the valency electron system of nitrogen which are not shared with the nucleus of another atom. However, there is no reason why this unshared pair should not hold a proton, H^+ , giving



Bearing in mind that H— always means H^+ —, it is clear that all the hydrogen atoms are united with nitrogen in the same way. We know that the ammonium ion shown above must have a deficit of one electron, because we regarded it as made from neutral NH_3 and a proton, but this can be confirmed by adding up the number of electrons (8) and the positive charges of the nuclei (9; 5 for N and 4 for 4H). This very simple operation is sometimes illuminating in more complex systems.

The representation of organic chemical reactions involves considerable bandying about of protons. These often change partners, as, for example, when an acid XH ionizes in water to give the hydrated hydrogen ion H_3O^+ . The neutral oxygen atom (with 6 electrons) can similarly be passed from one oxide, or peroxide, to another. Thus the substituted ammonia, trimethylamine, reacts with hydrogen peroxide (which may be looked upon as neutral H_2O plus an oxygen atom) to give an amine-oxide:



Langmuir was the first to point out that the elementary arithmetic mentioned above shows that N in the amine-oxide is positively charged and O is negatively charged. Although the distribution of the electronic atmospheres of the respective atoms should diminish the extent of the separation of the charges, there must be some residual dipole. This is, indeed, proved by direct measurement, and can be collated with a whole series of physical and chemical properties. We can express the nature of such a link by the symbols $(\text{CH}_3)_3\text{N}^+-\text{O}^-$ or $(\text{CH}_3)_3\text{N} \rightarrow \text{O}$.

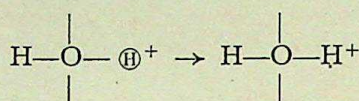
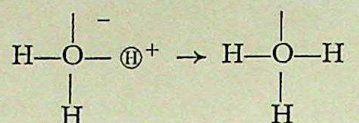
All the so-called co-ordination compounds—formed from certain metallic salts and ammonia, amines, water, and so on—are produced by attack of unshared electrons on the nuclei of the metals. Hence Sidgwick called this type of link the 'co-ordinate link.' In all these cases it is apparent that when A— and B combine to form A—B, A is the electron donor and B is the electron acceptor. Adopting plausible analogies, it is possible to extend the allocation of donor and acceptor functions to other molecular species for which there can be no arguing from such elementary first principles.

Lapworth made the appropriate valuable extension of Berthollet's tables of affinity more than thirty years ago. He called the electron donors *anionoid* reagents and the electron acceptors *cationoid* reagents. By these terms he implied substances 'exhibiting a type of reactivity analogous to that of active anions and cations respectively'. He did not suggest that an anionoid reagent must be negatively charged. Ingold later introduced the terms 'nucleophilic' for anionoid and 'electrophilic' for cationoid. These are perfectly satisfactory equivalents, but the novelty is confined to the nomenclature, which expresses no fresh idea.

ANIONOID AND CATIONOID REAGENTS

The relationship between anions and anio-

noid complexes is seen from the comparison:



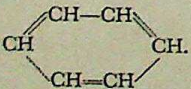
showing that the type of union of O and H is exactly the same in the two cases. Again, we have the active cations, such as those of the diazonium salts, $\text{C}_6\text{H}_5\text{N}_2^+$, and atoms with incomplete electron configurations, such as O and certain metals—for example, Co and Pt in their salts.

It had long been recognized that reducing agents are electron donors—metals such as Na and Zn giving up electrons and becoming cations—and that oxidizing agents are electron acceptors. Thus a ferrous ion, Fe^{++} , gives up electrons to become ferric ion, Fe^{+++} . Ferricyanide, $\text{Fe}(\text{CN})_6^{---}$, accepts electrons to become ferrocyanide, $\text{Fe}(\text{CN})_6^{----}$. It is a short step to deduce the cationoid character of the halogens, ozone, nitric acid, etc.

When we proceed to examine by analogy the electrochemical character of an alkyl group, e.g. CH_3 , we find, as might have been expected from the position of carbon in the periodic system, that it is almost neutral in itself but able to exhibit anionoid or cationoid character according to the electrochemical nature of the atom with which it is combined. In organo-metallic compounds such as zinc methyl, $\text{Zn}(\text{CH}_3)_2$, the metal is ready to give up electrons and the methyl groups are effectively anionoid in consequence.

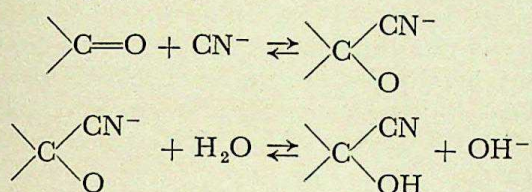
In alkyl halides, such as methyl chloride, CH_3-Cl , the halogen is avid of electrons and the methyl group is effectively cationoid as a result.

These results may be tabulated as follows:

<i>Electron Donors (anionoid)</i> Active anions, OH^-, CN^-. Anionoid complexes, R_2O, NR_3. Reducing agents; certain metal ions, such as Fe^{++}; $\text{Fe}(\text{CN})_6^{---}$. Organo-metallic compounds, such as R in RMgHal, RLi, R_2Zn.	<i>Electron Acceptors (cationoid)</i> Active cations, H^+, $\text{C}_6\text{H}_5\text{N}_2^+$. Atoms with incomplete electron configurations: O, Co, Pt, etc. Oxidizing agents; certain metal ions, such as Fe^{+++}; $\text{Fe}(\text{CN})_6^{---}$; halogens. Radical attached to potential anion, R.Cl, $\text{R}-\text{OSO}_2\text{C}_6\text{H}_5$.
Unsaturated carbon in ethylene, $\text{CH}_2=\text{CH}_2$, and benzene, 	Unsaturated carbon in carbonyl compounds such as formaldehyde, $\text{H}_2\text{C}=\text{O}$, and acetone, $(\text{CH}_3)_2\text{C}=\text{O}$.

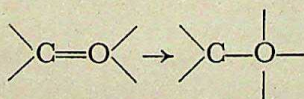
The additions to the table below the line are of great importance. They are made without taking mechanism into account and simply as a recognition of a characteristic type of reactivity. They find a place not merely on consideration of their interactions but on consideration of the electrochemical character of the group or atom which becomes attached to groups such as >C=O in ketones.

Thanks in large measure to the researches of Lapworth, there was from an early date a clear example in the case of the formation of cyanohydrins. The CN^- anion attacks (reversibly) the carbon of >C=O , and the complex ion so formed attacks some proton donor, such as water, producing cyanohydrin and a new anion:

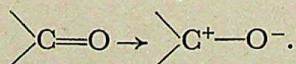


The whole chemical behaviour of carbonyl compounds is consistent with the conception that the carbon of >C=O is cationoid. Another example is the reaction with organo-metallic compounds, whereby the anionoid alkyl group becomes joined to carbon of carbonyl. Naturally, this does not mean that the carbonyl group as a whole is inert towards acids as sources of protons. The result of such interaction would be a protonide, e.g. >C=OH^+ , and in this entity the electron-attracting propensities of the carbon atom will be greatly enhanced by the net positive charge of the molecule.

Inspection will show that the electrons of the carbonyl group undergo a displacement in the course of the addition of cyanidion:



An electron pair has broken away from C and remains attached to O. This is a completed displacement and could be represented as

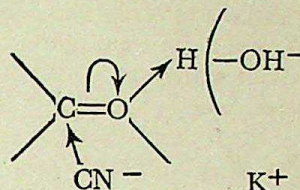


The writer wished, however, to express also a fractional displacement of the same type and for

this purpose introduced the symbol $\curvearrowright$. In

the present case, >C=O means a breaking

away from C (but remaining with O) of electrons covalently binding C and O, the extent being undetermined and up to a maximum of two electrons. Furthermore, there is no evidence that the steps in cyanohydrin formation are sharply defined, as suggested above, and the whole process may be represented by the expression



Union of O with H probably begins before the cyanidion has established a full covalency with C.

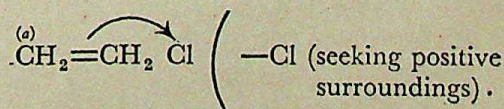
Turning now to unsaturated carbon in such groups as C=C , we find that the characteristic, facile reactions are with cationoid agents—for example halogens, oxidizing agents in general, or acids. On the other hand, this kind of unsaturated carbon does not combine easily with organo-metallic compounds, amines, or cyanidion. It is true that under special conditions some of these reactions can be forced, but they are not characteristic. Hence ethylene and its analogues are anionoid and their reactions are at least initiated by exhibition of an electron-donor property

symbolized by $\text{CH}_2=\text{CH}_2 \xrightarrow{(a)} \text{CH}_2=\text{CH}_2 \xrightarrow{(b)}$. This represents

a polarization of undetermined magnitude, and it is the unshared electrons, or fractional electrons acquired by (b), which seek centres of electron-defect in other molecules. The electron defect on (a) will be made up by the approach of anionoid centres at some stage, and probably before the new covalency with (b) is fully established.

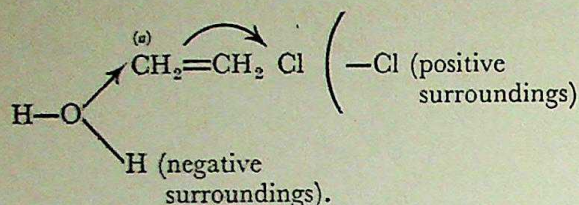
As another example of the use of our symbolism for almost synchronous processes the formation of ethylene chlorohydrin from ethylene, chlorine, and water may be mentioned.

1st stage



2nd stage

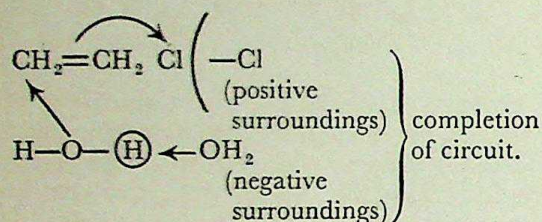
When the defect on (a) is large enough it is neutralized by an anionoid water molecule.



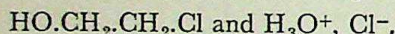
3rd stage

For the reason discussed above in relation to amine-oxide, the water molecule becomes positively charged, and a proton is lost to form H_3O^+ with another H_2O molecule.

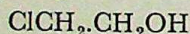
The complete circuit is therefore



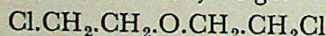
The electron pair can move round the circuit to the limited extent required, until we get



This process has also been interpreted as the addition of HOCl to $\text{CH}_2=\text{CH}_2$, but kinetic experiments have not favoured this view and have shown, *inter alia*, that the chlorine molecule is enormously more reactive than hypochlorous acid. In addition, the process can be carried out in alcohol (ROH) instead of in water, and the result is then $\text{RO} \cdot \text{CH}_2 \cdot \text{CH}_2 \cdot \text{Cl}$. In fact, as



accumulates in the solution, we get



as a by-product. A cyclic scheme like this has the great advantage that it avoids the large energy changes which independent ionization would require. In the cycle we gain on the swings what we lose on the roundabouts.

M. J. S. Dewar, followed by a number of modern investigators, has predicated a stage before the first of those given above. The π -electrons, which are those active in double bonds, are supposed to form a π -complex such as

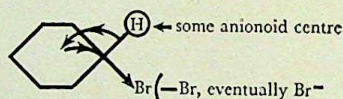


This conception has a certain resemblance to the old ideas of residual valency, which were, for example, brought into service to explain the nature of hydrocarbon picrates. It is of philosophic interest in connection with absolute mechanism, and has some practical bearing on certain stereochemical aspects of reaction processes. It does not, however, help much in orientation problems, that is, in predicting the direction taken by the chemical change being examined.

The π -complexes, if formed at all, must be very labile, and when they break down they form one or other of the systems which we have represented with the aid of the curved and straight arrows. It is a stage that in the majority of cases we can very well omit for practical purposes.

The facile reactions of benzene and its closer analogues are with the more powerful cationoid reagents, and in no case with anionoid reagents. The products are, however, obtained by substitution rather than by addition, because of the power of resisting disturbance which the very stable electronic configuration of benzene confers on the molecule.

As an example we may take the bromination: $\text{C}_6\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_6\text{H}_5\text{Br} + \text{HBr}$. The overall processes can in this case be represented as follows:



In this simplified expression the curved arrows represent merely unsaturated electrons taken from the nucleus to form a link with a bromine atom and other electrons returned to it in compensation.

CONJUGATIVE ELECTROMERIC
DISPLACEMENT

A large part of organic chemistry is concerned with systems made up of various combinations of the anionoid and cationoid groups (and their obvious analogues; for example SR_2 with OR_2 and NR_3 ; $\cdot\text{CN}$, $\cdot\text{NO}_2$, $\cdot\text{NO}$ with $\cdot\text{CO}$). Thus, if we join together two anionoid complexes of the R_2O , R_3N type we get the hydrazine and peroxide systems, $\text{R}_2\text{N} \cdot \text{NR}_2$, etc. Two strongly cationoid groups of the carbonyl type afford the α -diketone, $\text{R} \cdot \text{CO} \cdot \text{CO} \cdot \text{R}$, system (related, by extension, to the quinones).

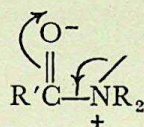
Neutralized system

A very instructive case is the union of a strongly anionoid and a strongly cationoid group. This the

writer has called a 'neutralized' system, because the typical reactivity of each centre is diminished by intramolecular electromeric displacement. Thus, in the amides we have $R'(C=O).NR_2$ (unshared electrons), and the separate reactivities

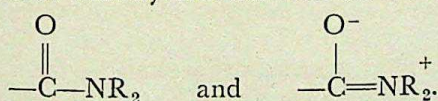
are indicated in the symbol $R' \overset{\curvearrowright}{\underset{\text{O}}{\parallel}} C - NR_2 \rightarrow$.

The way is open for internal satisfaction of the opposing tendencies, and the actual position is

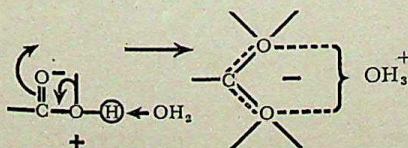


which implies a number of properties.

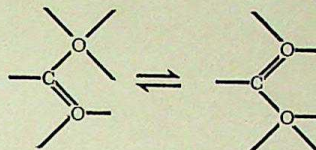
1. That the resting molecule is a dipole; this is confirmed by actual measurement of the dipole moment. The dipole is the cause of the molecular association of the amides, which in turn is evinced by a relatively high boiling-point. Nylons are substances whose long-chain molecules contain amide groups, and the disposition of the dipole groups in contiguous chains is one of the important factors affecting the physical properties of the assemblages of macromolecules. The writer may perhaps be permitted to say that this view of amides (and of carboxylic acids and esters) was expressed by him in partial valency form in 1920, and was used in lectures and teaching from 1922 in the electronic form; it was repeated specifically in 1926. At first the exponents of the resonance theory overlooked this and put forward the conception that the amides were hybrids between the extremes:



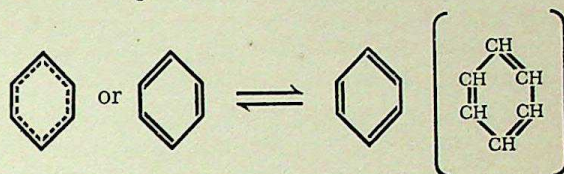
That is precisely the meaning of the expression with curved arrows quoted above, and after some years this method of representing resonance (or mesomerism) has been widely adopted. Carboxylic acids and esters are quite similar in kind, though not in degree, in their electromeric displacement; the 'acidity' of the carboxyl group is evidently due primarily to the repulsion (or weaker attraction) exerted on the proton by the positively charged oxygen atom.



In the carboxyl ion it is impossible to distinguish between the oxygen atoms, so that this looks like a case where $\curvearrowright$ means the displacement of one electron. Nevertheless, the wave mechanicians may not approve of this and may prefer a dynamic, or extremely labile, system:



The problem is similar to that presented by the benzene ring:

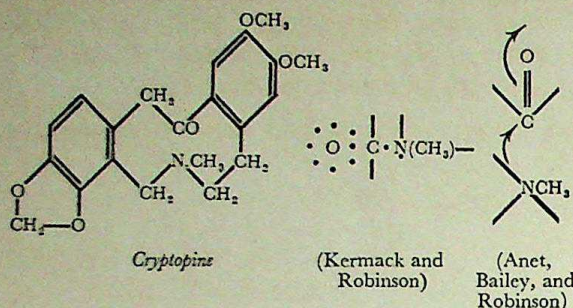


2. That the cationoid character of the carbonyl must be diminished; this occurs in varying degree. It is never entirely suppressed, as is shown by the reaction of suitable amides with organo-metallic compounds or with reducing agents such as metallic sodium or lithium aluminium hydride. In esters the carbonyl group is more active than in amides, because OR_2 is a weaker electron donor than NR_3 . Condensation reactions of the Claisen type are manifestations of the cationoid carbonyls, and so are the ester exchange reactions under the influence of RO^- anions. Nevertheless, the carbonyls of amides, carboxylic acids, and esters are definitely less reactive than those of aldehydes ($R.CO.H$) or ketones ($R.CO.R'$).

3. That the anionoid character of the amine moiety of amides should be reduced. It is apparent that if we use the unshared electrons within the molecule to a certain extent, they will to the same extent be unavailable for donation to protons or other cationoid centres externally. Hence the amides are far weaker as bases than the amines from which they are derived. This is one of the facts about amides which is learned in the most elementary study of the subject. Again, the basic strength is only greatly diminished; it is not entirely suppressed.

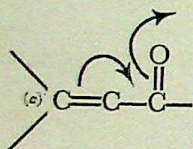
Amide-type neutralization of $>C=O$ and NR_3

across intramolecular space was suggested by the writer in 1922 (with W. O. Kermack) in the case of cryptopine, and was experimentally confirmed in 1953 (with F. A. L. Anet and A. S. Bailey) in this and other examples.



Catio-enoid systems

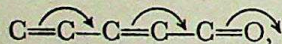
Ethylene is a weaker anionoid group than ammonia, and direct union of an ethenoid (unsaturated) carbon group with a carbonyl group produces a correspondingly weaker neutralization of the carbonyl reactivity. The system is not so tightly knit as in the amides, and each moiety can function independently. Nevertheless, the conjugative electromeric displacement represented by the symbol



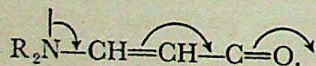
is a potentiality very frequently realized in practice.

This displacement has the very interesting effect of transferring the electron defect of the carbonyl carbon to the terminal carbon of the ethenoid system. The latter thus becomes cationoid at (a). Thus the quality of reactivity of the carbonyl group has been transferred to the ethenoid centre (a), and this group can now be attacked by cyanidion and other active anions and anionoid reagents.

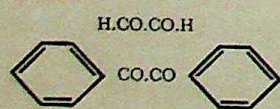
Still more extended systems are possible, for example



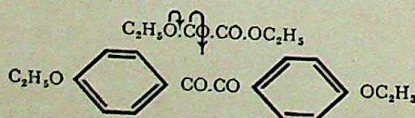
and we can combine the catio-enoid system with an anionoid complex,



The expected properties have been noted in the laboratory, and an example which the writer has used is given by the following comparisons:

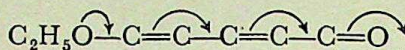


Yellow, and reactive in a cationoid sense.



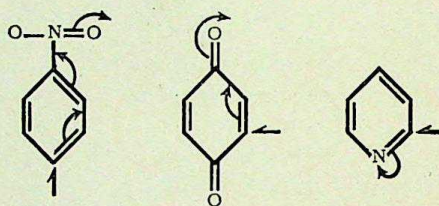
Colourless, and much less reactive in a cationoid sense.

In the group $C_2H_5O.CO$, we have a directly neutralized system, as above. In



the neutralization operates through two double bonds.

Catio-enoid systems are at work in many reactions of aromatic systems with anionoid reagents, and some of the better known types are: (1) the hydroxylation and amination of nitrobenzene; (2) the Thiele acetylation of quinones; and (3) the Tschitschibabin amination of pyridine.



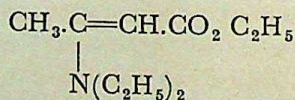
The sign $\leftarrow$ indicates the point of entry of the anionoid reagent. It will be seen that the three types are distinguished by the position of the cationoid group, which can be (1) wholly outside the nucleus, (2) partly in the nucleus, and (3) wholly in the nucleus.

Apart from these and similar types, the reactions of aromatic compounds are always with cationoid reagents.

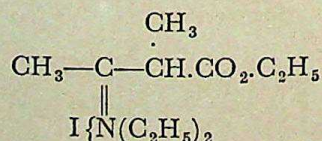
Hetero-enoid systems

The writer's interest in these topics arose to a large extent in the study of the reactions of substances of this class from 1915 onward. The processes were interpreted in terms of partial valency symbols, which were translated into electronic terms from about 1921.

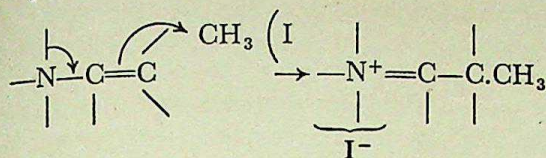
In these systems an anionoid complex (or anion, such as $-O^-$) is directly attached to an ethenoid group and powerfully reinforces its anionoid reactivity. Thus,



on combination with $CH_3.I$ yields

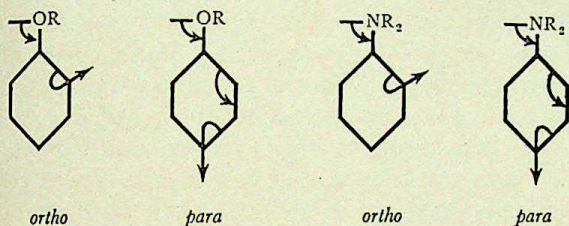


the process being



The most important examples of such systems are the aromatic amines and the phenols.

The reactivity of benzene towards cationoid reagents (diazonium salts, bromine, nitric acid, sulphuric acid) is enormously increased by the amino or hydroxyl substituent, and the position taken up by the entering group is determined as *ortho* or *para*:

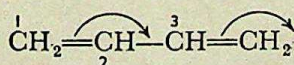


Apparently paradoxically, the activity of unshared electrons is greater the smaller their number, $N > O > F$, the reason being the approach to the rare-gas configuration as the number increases. Nevertheless, even the halogens can take part in hetero-enoid systems to an extent sufficient to control the orientation of entering substituents derived from cationoid reagents:

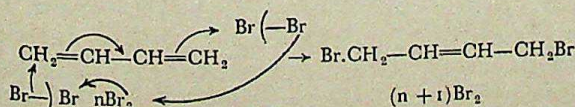


Polyenoid systems

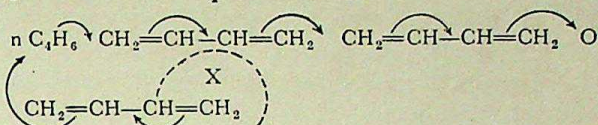
Here one ethenoid group reinforces another, as in the simplest case, that of butadiene,



Anionoid reactivity is enhanced, but by no means so markedly as in the hetero-enoid systems. The electron defect on C^3 is transferred to C^1 exactly as in the case of the catio-enoid systems. A completed additive process involves the movement of the double bond:



A characteristic reagent which induces polymerization of butadiene is a peroxide, and the process can be represented as:



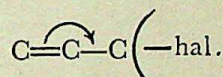
The end group at X must then react in some different manner. The reactions of benzene



are frequently represented as being similar to those of butadiene and it may well be asked—why does not benzene polymerize? The answer may be that the electromeric displacements in benzenoid substances have a very much smaller amplitude than those in butadiene, on account of the restoring force of aromatic stability.

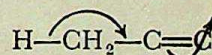
Other conjugated electromeric systems

The allyloid system



is well established, and also those involved in keto-enol tautomerism (including reducibility of α -halogeno-ketones), Hofmann and other elimination reactions, carbinolamine formation, and in a great variety of molecular rearrangements.

A doubtful position is occupied by what is called hyper-conjugation,



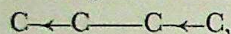
The writer thinks this is really hypo-conjugation, a second-order effect, if it exists at all. Certainly a great deal of the evidence advanced in favour of the phenomenon can be interpreted in a different manner, and the suggestion should be regarded as *sub judice*.

All these conjugated electromeric processes obey the rule of conservation of the electronic configuration of the atoms, and this rule discloses the position and electrochemical character of points of reactivity. In general, the effects are repeated at *oxye* positions.

It is now necessary to look at another kind of intramolecular electrical effect, one which was in fact the first to be recognized.

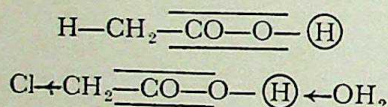
DIRECT (INDUCTIVE) ELECTRICAL EFFECT

J. J. Thomson pointed out that atoms, like those of chlorine, with a relatively large and concentrated nuclear charge (as compared, for example, with hydrogen or carbon) strongly attract covalency electrons binding them to atoms of lower atomic numbers. This follows from simple electrostatic principles, the electron atmosphere being diffuse. The result must be a drift of electrons represented by the symbol $\text{Cl} \leftarrow \text{C}$ and a dipole moment, $\text{Cl} \leftarrow + \text{C}$. Whether we consider a direct inductive effect through space or one set up in a series of contiguous condensers,



there is obviously here an important electrical effect which can be studied experimentally by a physical method and which should be capable of being collated with reactivity in regard to both rate and orientation. The simplest applications are to the strengths of acids and bases. Groups like $\text{O}_2\text{-N}^+ - \text{C}$ and $\text{Cl} \leftarrow \text{C}$ substituted for $\text{H} - \text{C}$, anywhere in the molecule, invariably increase the strength of an acid.

The positive field moves the electron sheath of the oxygens, and one interpretation of this is that the repulsion exerted by the oxygen nucleus on the attached proton is thereby increased. It is therefore relatively easier for a solvent molecule (such as H_2O) to detach it.



The above is naturally a purely pictorial expression, in which the parallel horizontal lines represent the electron atmosphere in the vicinity of the carboxyl groups of acetic and chloroacetic acids.

Predictions are fulfilled in examples involving groups and atoms of unequivocal chemical character. The effect, like all inductive effects, diminishes rapidly with increasing separation of the source of the disturbance and the carboxyl group. At a certain distance it becomes quite small and hardly observable. The following data for dissociation constants are typical:

$\text{CH}_3.\text{CH}_2.\text{CH}_2.\text{CO}_2\text{H}$	$K = 1.6 \times 10^{-5}$;
$\text{Cl}.\text{CH}_2.\text{CH}_2.\text{CH}_2.\text{CO}_2\text{H}$	$K = 3.0 \times 10^{-5}$;
$\text{CH}_3.\text{CHCl}.\text{CH}_2.\text{CO}_2\text{H}$	$K = 8.94 \times 10^{-5}$;
$\text{CH}_3.\text{CH}_2.\text{CHCl}.\text{CO}_2\text{H}$	$K = 1.39 \times 10^{-3}$.

The difference between a factor of 3.0 and one of 1.6 is only just significant in this field. The step from 3.0 to 8.94, however, is beyond the limits of

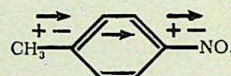
experimental error. The large change when the chlorine atom moves from the β - to the α -position is unmistakable, and is characteristic of the inductive effect.

A study of the effect on the strength of acids and bases resulting from substitution of hydrogen by alkyl groups indicated the possibility that the group $\text{CH}_3 - \text{C}$, as compared with $\text{H} - \text{C}$, distributes a negative electrical field, $\text{CH}_3 \rightarrow \text{C}$, but the values observed were always too small to have clear significance.

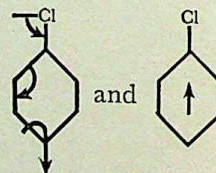
$\text{H}.\text{CH}_2.\text{CO}_2\text{H}$	$K = 2.1 \times 10^{-5}$
$\text{CH}_3.\text{CH}_2.\text{CO}_2\text{H}$	$K = 1.4 \times 10^{-5}$
$(\text{CH}_3)_2\text{CH}.\text{CO}_2\text{H}$	$K = 1.5 \times 10^{-6}$
$(\text{CH}_3)_3\text{C}.\text{CO}_2\text{H}$	$K = 9.8 \times 10^{-6}$

A better answer was given by studies of dipole moment in the aromatic series. The moment of *p*-nitrotoluene was found to be approximately the sum of that of toluene and of nitrobenzene.

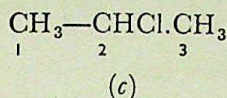
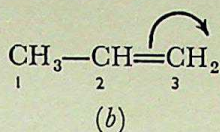
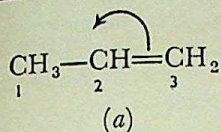
The direction of the displacement caused by the nitro group is known, and hence that caused by the methyl group must be in the same direction in the molecule of *p*-nitrotoluene. That means that it is of opposite electrical character, as illustrated in the accompanying diagram, in which the arrows indicate the direction of electron drift:



L. E. Sutton made a great contribution by demonstrating experimentally, by measurement of dipole moments, that an electromeric effect in which electrons move into the benzene nucleus can co-exist with an inductive effect such that electrons drift in the opposite direction. Thus

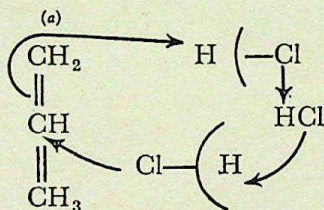


can occur together in the molecules. Roughly speaking, the inductive effect controls rate of reaction of the molecule as a whole and the electromeric effect controls orientation, with the very important qualification that where there exists more than one potential electromeric process, the electrical fields over the whole molecule may decide which of the possible systems is operative, and in which sense. This is an indirect control of orientation, and an example is provided by additions to simple unsymmetrical ethylenes:



Propylene could undergo electromeric polarization as in (a) or as in (b). But the electron push (relative to H) of the CH_3 group (see above) evidently favours (b). Hence the anionoid centre is C^3 , and at this point the cationoid H of HCl is taken into the molecule, leaving C^2 to combine with Cl^- .

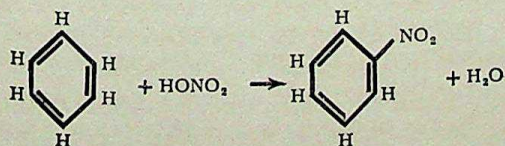
Once again, the purely ionic interpretation is too crude. Many writers nowadays would say that a carbonium ion, $\text{CH}_3\text{C}^+\text{H}\text{CH}_3$, is formed, and that this then combines with chloridion. The writer considers that all such processes go through gradations in a cycle, and that Cl^- begins to go in before the union with H^+ is completed,



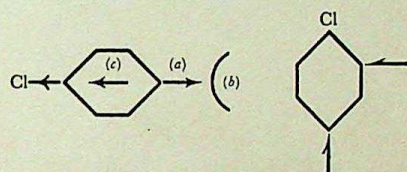
but the cycle is initiated by (a).

SUBSTITUTION IN THE BENZENE NUCLEUS

The example above is one in which Markownikov's rule (that the halogen atom combines with the carbon already joined to the greater number of carbon atoms) applies, and the agreement with prediction is excellent over the whole field. In this open-chain series there are nevertheless certain complications, such as the two modes of addition of hydrobromic acid (one in the presence and the other in the absence of peroxides), the arguable importance of steric factors, and, on the practical side, the difficulties encountered in separation and analysis of the products of reaction. Almost all these doubts and difficulties are less, or even non-existent, in the study of substitutions in the benzene series; by this we now imply substitutions by means of cationoid reagents. The most widely used of the latter is nitric acid, which affords nitro-compounds, often in very high yield:



In recent years, studies of the kinetics of nitration in the presence of sulphuric acid have been interpreted (Bennett, Ingold) with the aid of the theory that nitronium, NO_2^+ , is the active agent. It is hard to credit that this is universally true. For example, in facile nitrations in aqueous or acetic acid solution, formation of a cationoid complex, NO_2^+OH , seems more probable. The point is immaterial for the present discussion, however, as the reagent is certainly cationoid. Hence sites of nitration ($\leftarrow$) are simply points in the ring where unshared electrons may be found and where the subsequent processes can be completed. If these electrons are represented below by (a) and the cationoid reagent approaches from (b) then a positive field, indicated by (c), will tend to inhibit the formation of the new covalency by binding (a) closer to the carbon atom of the nucleus:

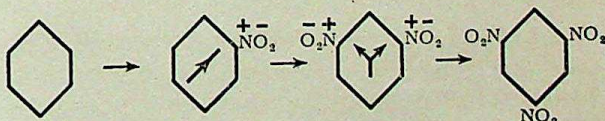


Because of the electrical field set up by the Cl^-C^+ dipole, the nitration of chlorobenzene, $\text{C}_6\text{H}_5\text{Cl}$, is much slower than that of benzene. Toluene represents the opposite case:



The field in this instance facilitates substitution: toluene nitrates faster than benzene. These, it must be realized, are not electromeric effects in themselves, and, as was discussed in the case of strength of acids, the operation is from almost any part of the molecule on any part of the molecule.

The nitro group is itself dipolar, so that the difficulty of nitration increases in the series benzene, nitrobenzene, dinitrobenzene:

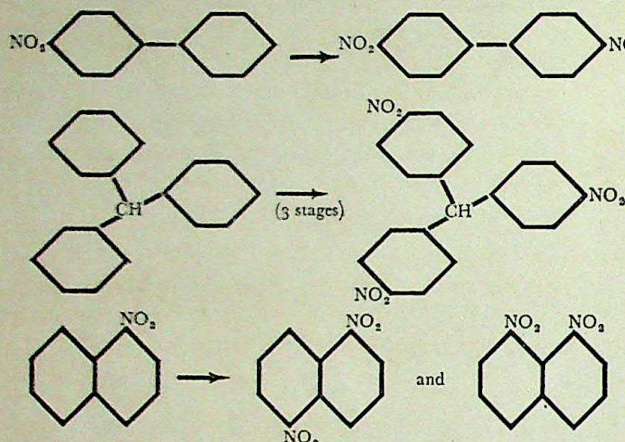


In fact, the last stage, to trinitrobenzene, is so difficult to effect as to make it impracticable on an industrial scale.

Working some years ago in Oxford, G. Müller found that nitration to trinitrobenzene could be effected with a cold mixture of nitric and perchloric acids, but this is a method which is hardly

likely to recommend itself to a manufacturer. The trinitro-compounds have valuable properties as explosives, and the one made on a large scale is trinitrotoluene (TNT), because the increase of reactivity produced by the methyl group is sufficient to enable us to reach the trinitro stage in a convenient process.

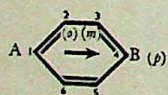
Since the inductive effect dies away as the source of it becomes more distant, we naturally find that substances whose molecules contain more than one benzene ring nitrate first in one nucleus and then in another:



The extreme stability of pyridinium salts towards cationoid agents is due to the fact that the nucleus is positively charged. Hence any unshared electrons produced in electromeric processes are very tightly held and are, in fact, almost inert:

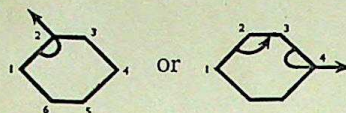


If we now consider a benzene nucleus under the influence of a field such that electrons



tend to move in it in the direction of the arrow (the *ortho*, *meta*, and *para* positions being expressed relative to A) it is evident that this can be produced by an electron push from A or by a pull from B. The former will, as we have seen, result in increased reactivity, and the latter connotes a decrease of reactivity. The push must operate most strongly from C¹, and the pull will be strongest at C⁴ and weakest at C¹. The electron potential will therefore fall in the series C¹, C², C³, and C⁴. The most facile electromeric process

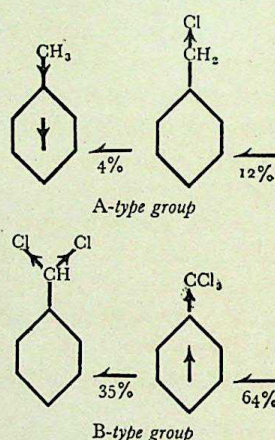
must accordingly be something originating from C¹, either



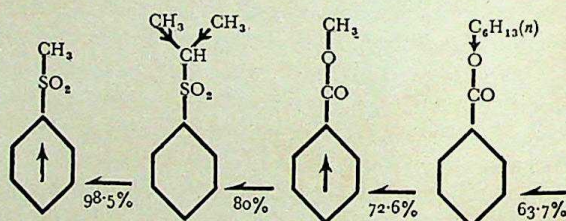
Thus an (A) group causes nitration in the *ortho* and *para* positions with greater ease than in benzene.

For exactly the same reason a substance containing a (B) group is nitrated in the *meta* position (*ortho* to A in the diagram) or, as often happens, the (B) group is itself displaced (*para* to A in the diagram).

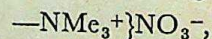
If we start with a group of (A) character we can—by introduction of halogen atoms, nitro groups, or ammonium centres—effectively convert it into a (B) group:



The figures indicate the percentage yield of *meta* derivative according to the nature of the original substituent. Transformation of a B-type group to an A-type group is less easy:



A quaternary ammonium salt grouping,



produces completely *meta* nitration when it is directly attached to the nucleus; substantially more than 90 per cent *meta* nitration when separated from the nucleus by one carbon atom; but when two carbon atoms distant from the nucleus, the *meta* nitration drops to 10 per cent. A nitroxy ($-\text{NO}_2^+$) is about equivalent to ($-\text{NH}_3^+$) in this series, but it must be remembered that amines

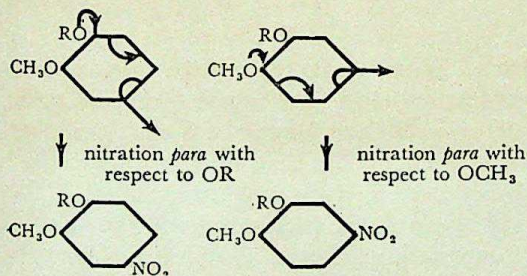
bearing a hydrogen atom on the nitrogen do not exist entirely as salts, even in strong acid solution. The non-onium moiety, though minimal in concentration, nitrates rapidly.

As already stated, the conjugated electromeric systems are dominant in orientation, and yet the orientating power of hetero-atoms (O, N, etc.) directly attached to the nucleus can be modified by field effects.

It occurred to us at Manchester to test the hypothesis of the combined electrical effects by studies in the catechol and quinol series, and an interesting contrast between the two was noted. The outcome was readily explicable on the molecular field hypothesis, and may indeed be regarded as a proof of its essential correctness.

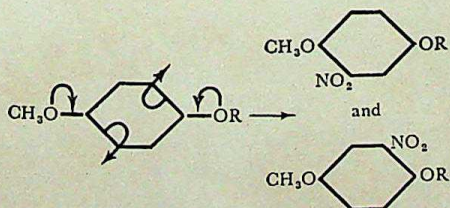
The alkyl ethers of both catechol and quinol are practically quantitatively mono-nitrated in acetic acid solution by not much more than the theoretical amount of nitric acid. In the catechol ethers the substitution is exclusively *para* to oxygen, and in the quinol ethers there is nothing except *orthonitration*.

The substitutions are both due to activation of two electromeric systems of the hetero-enoid type, and when two different alkyl groups are used on the two oxygens the orientating power of the two systems must be different. In our experiments one of the groups was always methoxyl:



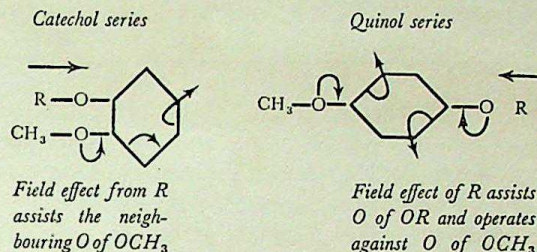
These products could be independently synthesized, and, by means of a melting-point curve for mixtures of the two isomerides, any mixture produced in the nitration could be accurately analysed.

The case of the quinol ethers is exactly parallel:

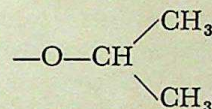


It was in fact found that the orientating power of

OR, even when R was a higher alkyl group, could be varied considerably. For example, we found the directive power (taking CH₃O as 100) of the group CH₃—CH₂—O— to be 135 in the catechol series and 164 in the quinol series. The explanation is that any push from R producing a field effect must help both oxygens in the catechol series (thus diminishing the disparity) but will help one oxygen and hinder the other in the quinol series:



Thus, as the field effect of R was increased the orientating power of OR in the quinol series rose continuously, until with C₁₆H₃₃O it was as much as 212. But in the catechol series the orientating power reached a maximum (150) at



and then fell. The reason was clearly that the field was more and more distributed over both oxygen atoms as the alkyl chain was increased in length.

In this brief review no attempt has been made to cover the subject, but merely to give the elementary theoretical background for a limited number of plain examples of the operation of a molecular electrical field on a reactive centre.

In conclusion, the writer would like to point out that the charges on the nuclei of the atoms are as important as those on the electrons, and this is especially true in comparisons of stereoisomerides and the like. When two conformations are possible, the more stable should be that in which the nuclei of the atoms achieve the greater separation. Thus, a *trans* form of a disubstituted ethylene should be more stable than an isomeric *cis* form, and this is well known to be so. The greater stability of the chair form of cyclohexane as compared with the boat form is another example of the tendency to gain stability by a maximum separation of the nuclei. It is simply a special case of a more general rule, and it may be well to remind ourselves that in the last resort the whole molecule, and not just a part of it, must be considered in estimating the degree of *trans* quality.

On keeping wild animals in zoos

A. URBAIN and J. C. G. NOUVEL

The keeping and breeding of animals in captivity is both of direct zoological importance and of general educational interest, and in recent years has been the subject of considerable research. Much has been learnt of the needs of many species in regard to accommodation, diet, and the prevention and treatment of disease. Of particular interest is the demonstration of the fallacy of the belief that animals in the wild are free to roam at will; in point of fact very many factors restrict their movements and the natural state is not one of freedom.

From the earliest times, man has exhibited in public places all manner of wild animals—elephants, bears, lions, tigers, hyaenas. The ancient Egyptians were past-masters in the exhibition of wild animals and used the same methods as we do today for capturing their specimens—nets, traps, living bait, and, for birds, nooses and bird-lime. Furthermore, the lay-out of their cages was on a system closely resembling that of the oldest of present-day zoos.

A modern zoo differs considerably, however, from the older establishments in the conditions of life provided for the animals. They are to be seen in natural settings, at liberty among stones or in grassy meadows. Water-fowl have lakes; birds of prey are housed among rocks on which they can easily find a perch.

Besides this, the animals must be able to run, to climb, to jump, or to fly, according to their habits, which involves giving them ample space. This is essential for the maintenance of good health; it is also a necessary condition for satisfactory breeding, though this depends even more on the provision of an adequate diet. Feeding and comfort are the two basic problems of raising wild animals in captivity.

HABITAT

The criticism most often made of the practice of keeping animals in captivity is directed against the limited space at the animals' disposal. This limitation is emphasized by the fact that animals in the wild seem able to roam at will, and that nothing prevents them from fleeing before the advance of man. Moreover, the bars which separate the animals from the spectators have unhappy associations with prisons.

These ideas are, however, largely fantasies. Observation shows that animals in the wild state are by no means able to roam about at will. The development of the concepts of region of dispersal,

biotope, and territory is based on recognition that an animal is limited in its movements not only by biogeographical conditions, but by the presence in its neighbourhood of predatory species or of animals of the same species that are maintaining their own territories. Migration is often thought of as a journey freely undertaken, but as we come to understand the underlying mechanism we find that the long and hazardous trip is in fact forced upon the animal by external or internal changes, such as the approach of cold weather or phases of sexual development. The state of nature is by no means a state of complete freedom.

An alleged proof that captive animals are cruelly restricted in the space available to them is the fact that they do not avoid man, as do almost all animals in the wild. However, flight is produced by the appearance of man only if he is regarded as an enemy. In the Antarctic, where man is rarely seen, and in the various national parks and game reserves, animals show no fear of man. Moreover, captive animals do not seek to avoid a spectator who draws close to their enclosure, though if this same visitor enters the enclosure itself, the animals will at once seek to escape. Only certain keepers, and these the most skilled at their profession, are able to attract some of the animals to themselves; in this the complete confidence they inspire in the animals is probably an aid. All this indicates that the avoidance of man by animals is not automatic, but occurs only when the animals regard man as inimical; the question of space limitation is quite irrelevant.

The earliest enclosures for wild animals consisted of pits or palisades. Cages were soon introduced, and are still to be seen in our older zoos; nowadays, however, there is a tendency for their bars to be replaced by less obvious barriers such as bodies of water or broad ditches. This improvement in technique has undoubtedly done more to remove the prison-like atmosphere of the older



FIGURE 1 – The graceful black swan, *Chenopsis atrata* (Latham), native of Australia, which has been nesting since January. This photograph and those that follow were taken at the Parc Zoologique du Bois de Vincennes and illustrate the great variety of wild animals for which suitable accommodation and diet must be provided.



FIGURE 2 – White pelican, *Pelecanus onocrotalus* L., interesting because of its curious shape and the use to which it puts its beak.



FIGURE 3 – The Eld deer, *Cervus (Panolia) eldi* M. Clelland, from the North of India and Indo-China, is now very rare. In Paris it maintains the seasonal rhythm that it follows in its native country.

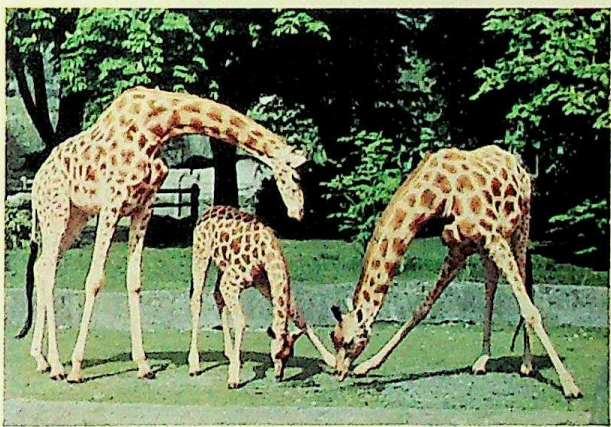


FIGURE 4 – Giraffes, *Giraffa camelopardalis* L. These are of a fairly common species, which has been reared in many zoological gardens.



FIGURE 5 – Polar bear, *Thalarctos maritimus* Phippe, an arctic species still only rarely reared in captivity, although it is represented in most zoological gardens.

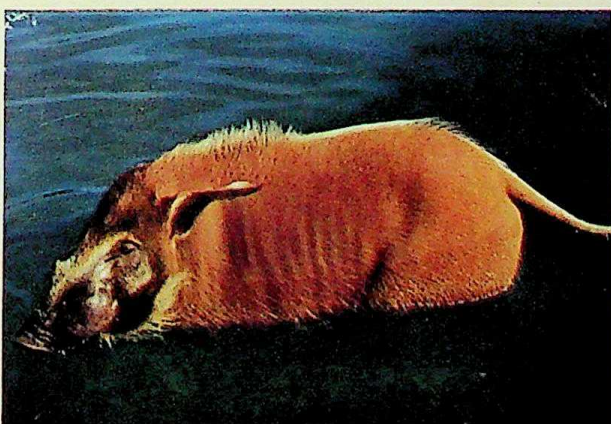


FIGURE 6 – Red river hog, *Potamochoerus porcus* L., African swine frequenting marshes and the banks of rivers.

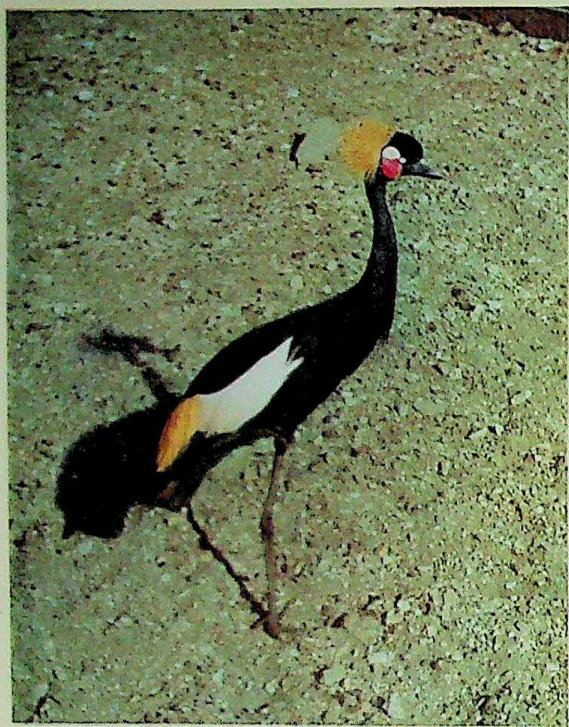


FIGURE 7 – Black-necked, or West African, crested crane, *Balearica pavonina* L. This African crane is characterized by the crest on the nape of its neck and by its cry, which is composed of two different notes.



FIGURE 8 – *Ciconia ciconia* L., migratory species of stork which winters in Africa and nests in Europe. Here its nest is at ground level.

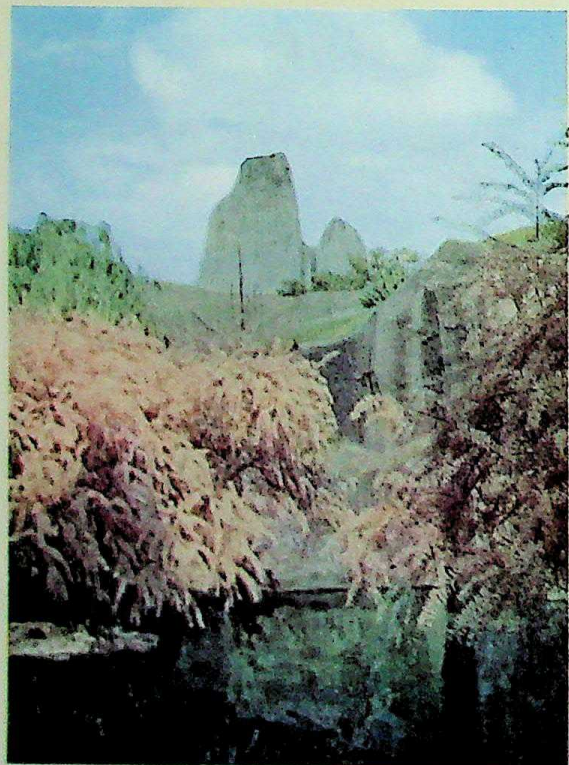


FIGURE 9 – Spring landscape in the Vincennes Zoo. The teal pool is surrounded by tamarisks (*Tamarix tetrandra*); in the background is the silhouette of the 'Grand Rocher.'

FIGURE 10 – The kitchen of the Vincennes Zoo. Here are prepared all foods which have to be cooked, as well as some special diets.



zoos than acceptance of the arguments given above. Progress can, however, be only slow, since much work has to be done for each species in turn in order to provide inconspicuous but perfectly safe barriers.

DIET

The problems of diet [1, 2] are as important as those of habitat. The first guide in fixing the diet of a captive animal is a study of its digestive system. Yet, even if systematists teach us to distinguish carnivores, herbivores, insectivores, and so on, observations on animals in the wild show that these terms are by no means absolute and that animals which consume only a single type of food are extremely rare. We are thus led to modify diets at present in use when relevant observational data of the wild state are acquired.

Another method of determining an animal's diet is to present it with several alternative foods and to note the ones it prefers. This method is most useful with recently captured animals, which are presented with foods obtainable from their natural habitat; it may be misleading when applied to animals accustomed to captivity. The latter may consume an excess of some palatable food to the exclusion of a necessary component of the diet, or may refuse a food regularly eaten in wild nature because they have become unaccustomed to it. An example of the first type is provided by several species which, when the zoo is crowded with spectators, will consume large quantities of bread, refuse their normal rations, and sometimes die as a result of indigestion. The second case is illustrated by captive animals which refuse one of the foods normally taken by their wild companions if it is presented to them. This refusal is usually only temporary, and a taste for the unfamiliar food is more or less quickly acquired.

The monkeys and apes, particularly the anthropoids (gorillas, chimpanzees, and orang-utans) [3], are particularly difficult to feed. What, for example, is the natural food of the gorilla [4]? This ape spends the hours of daylight in search of its food, which is varied. In the Cameroons it shows a great liking for a little red berry which is commonly found in small bunches. This berry contains a violet pulp, with an acid taste, enclosing a number of blackish pips which may be found in gorillas' faeces. The natives call this fruit the 'esson'; it belongs to a plant of the group Scitaminae. The gorilla also likes the buds of sugar-cane and the pith of the banana tree (which it prefers to the fruit). Termites are a special

delicacy, and it will also steal the eggs from birds' nests.

In captivity, the gorilla, like the other anthropoids, has different requirements. It needs a substantial and varied diet in a fresh and wholesome condition. The table below gives the daily rations of the female gorilla 'Solange,' which has been in captivity since 1931:

Cooked meat	250 g
Vegetables:	
Carrots	300 g
Cabbage or lettuce	2000 g
Cooked potatoes	150 g
Fruit, according to season:	
Peanuts	100 g
Bananas	250 g
Dates, figs, oranges, or apples	300 g
Bread	250 g
Milk	0.5 l
Eggs	2

The following table gives the daily ration of the chimpanzees at the Psychological Laboratory of Yale University, at New Haven, Connecticut; this laboratory is under the direction of Dr Yerkes. A chimpanzee weighing about 22 kg receives daily a ration of 1694 g, providing 2670 calories. This ration is made up of a special biscuit ('chimi-cracker'), supplemented by fruits and vegetables.

<i>Composition of biscuit</i>						<i>g</i>
Wheat flour						1200
Toasted wheat						2200
Maize flour						2200
Crushed oats						1000
Powdered bones						350
Powdered milk						400
Salt						50
Peanut butter						1200
Raisins						920
Molasses						455
<i>Composition of supplement</i>						<i>g</i>
Cabbage						150
Carrots						175
Onions						125
Bananas						300
Oranges						230
Potatoes						200
Milk						50
Peanuts						114

The daily ration consists of 350 g of biscuit and 1344 g of fruit and vegetables. The chimpanzees on this ration keep in excellent health and breed well.

Variety in the diet is not in itself enough to ensure the maintenance of life. Some species have particular requirements. An example is the white-coated Colobus monkey (*Colobus abyssinicus occidentalis* Rochbrune). This monkey will survive in captivity only if it receives an abundance of leaves of the vine (*Vitis vinifera* L.), mulberry (*Morus alba* L.), or aucuba (*Aucuba japonica* Thunb.). These cannot be effectively replaced by salads, cabbage, cress, spinach, or any kind of fruit. What is it that these leaves contain that makes them essential to the animals' survival? It is unlikely to be a known vitamin, since the other vegetables contain vitamins, and vitamin supplements fed to the animals have been found to be ineffective. We think it is more probable that the leaves contain minute quantities of certain other factors, whose effect on the tissues has been demonstrated by Gabriel Bertrand.

The food of carnivores is not usually restricted to lean meat. The great felines, which traditionally receive such a diet in captivity, in the wild state eat certain vegetables, and also the viscera of their victims, particularly the liver. The latter is known to be rich in biologically essential substances, as is illustrated by the large number of medical preparations into which it enters more or less directly. On the other hand, the canines and hyaenas possess a powerful digestive system and can live a healthy life, and even reproduce in captivity, on a diet composed exclusively of meat. In the wild state, nevertheless, these animals, too, have a most varied diet, as is shown by the list of foods consumed by the fox in the wild state [5]. The rearing of certain foxes for their fur has revealed some requirements of these animals that had not become apparent under the less exacting conditions of the zoo. The mustelidae and the civets, although allied to the carnivores, are much less easy to satisfy in their feeding requirements.

Contrary to the impression which these examples may have given, it is not always safe to assume that related families of animals have similar nutritional needs. With mammals in general one can assume the same diet to be appropriate to a whole zoological family, but there exist specimens whose requirements are very different from animals nearly related to them. The fennec fox (*Fennecus zerda* Zimm.), for example, is as nice in its choice of food as the other foxes are catholic in theirs, and the ferret (*Mustela putorius furo* L.), which can live and reproduce in captivity on a diet consisting exclusively of bread and milk, differs in this respect from most of the other mustelidae.

The problem of feeding herbivores is quite different. In the wild, these animals may partake of 50 to 100 different vegetable species [6-9]. In captivity, no attempt is made to reproduce such a diet, and the feeding is usually based more or less on the known needs of similar domestic species. The multiplicity of plant types comprised in ordinary forage crops is usually enough to provide a satisfactory regimen for the captive herbivores, and even to enable them to reproduce. In some cases, however, a special diet is necessary. The best known example is the roe-deer (*Capreolus capreolus* L.), which, although common in the French forests, is difficult to keep in captivity in spite of the daily provision of the leaves of blackberry (*Rubus idaeus* L.) and ivy (*Hedera helix* L.) which in nature make up the greater part of the diet during the cold weather. Other examples are the giraffes (*Giraffa camelopardalis* L.), which reproduce consistently at the zoo at Vincennes. In addition to their ration of forage and grains, they receive oat flakes, carrots, bananas, onions, cress, and branches of the locust-tree (*Robinia pseudacacia* L.) during the seasons when this is possible.

Following the work of Raybaud [10], and of Urbain and Guillot [11], we feed to all our herbivores a substantial quantity of germinated grain. The grains are soaked in water for 24 hours and then kept in special containers for 2 to 3 days, until the radicle emerges. The animals prefer these to dry grains. The experiments quoted above have shown that animals on this diet put on more weight and keep in a better condition, but the biological reasons for this result have not yet been discovered.

Other observations have shown that, in the present state of knowledge, the best method of ensuring a satisfactory existence for captive animals is to supplement a balanced basic ration with small quantities of very varied foods.

PATHOLOGY

Satisfactory nutrition has the additional effect of reducing the incidence of disease, but the pathology of animals in captivity is none the less of great importance. Certain virus diseases are particularly feared in zoos, which from time to time introduce animals collected in all parts of the world. Rinderpest, detected simultaneously in London and Paris in 1865 by Bouley [12] and Leblanc [13], is as contagious as foot-and-mouth disease, whose rapid spread is all too well known. These two diseases attack mainly animals with cloven hooves (e.g. bovines, pigs). They constitute a serious menace to

domestic animals, and in consequence all countries impose severe measures to prevent their spread. Bouley has shown that, in zoos, strict isolation and rigid precautions can limit their spread without the need for a policy of wholesale slaughter. Swine fever is just as contagious, but happily it attacks only commoner and less important species. A form of typhus found among zoo carnivores, which has not yet been transmitted to domestic species, is a serious menace, but it can be prevented from appearing by a vaccination procedure due to Urbain [14].

Among birds, roup is fairly uncommon, and Newcastle disease has not yet been encountered in zoos. The most important disease is psittacosis, which again is the subject of strict health precautions, the more so because it is transmitted easily from birds to man, in whom it often proves fatal.

Microbial infections also cause trouble in zoos. Anthrax and glanders are spread among carnivores by the accidental feeding of infected meat. The organisms responsible for swine erysipelas and pseudotuberculosis do not usually cause severe outbreaks of disease, but they appear from time to time in a number of species of mammals and birds, as do other *Pasteurellae* and *Salmonellae*. Tetanus and botulism are rare, but various types of gangrene frequently occur; these can be overcome nowadays by the use of the appropriate antibiotics. Tuberculosis is a serious zoo disease [15]; it is fairly common in mammals and birds, causing 10–20 per cent of all adult deaths. However, it seems to be on the decline at present, and Ratcliffe [16] has shown that correct feeding can lessen its incidence.

Parasitic diseases are important, though somewhat less widespread. The commonest fungal parasites are species of *Aspergillus*, which mainly attack penguins and young geese. Keds (sheep-ticks) cause little trouble even when present in large numbers, but mites on birds, and those which

cause mange in mammals, were a serious problem until the modern synthetic insecticides were introduced. Unfortunately, these substances are toxic to reptiles and to the smaller mammals and birds.

Finally, the zoo pathologist is faced with wounds and accidental injuries which each year produce a number of fatalities. Medical aid is often of little help in these cases, but a careful study of their causes in relation to the animals' behaviour can often prevent their recurrence.

ANIMAL PSYCHOLOGY

Psychological analysis of animal behaviour is one of the most fruitful studies that can be carried out in a zoo. The behaviour of the animals in relation to the available space and to the physical factors of their surroundings plays a large part in the organisation of the zoo. The reaction of certain animals to others of different species governs the relative positions of the different enclosures, and intra-specific relations govern the make-up of groups or herds in which mortal combats can often be prevented only by building up a social hierarchy such as is found in the wild state. Finally, the behaviour of the animals towards man will influence the practice of those in charge.

Apart from their direct importance in the running of zoos, however, these observations have a greater interest when they concern advanced species, whose cerebral and psychic development approach that of man. The line of approach pursued by Koehler and Yerkes, and followed subsequently by others, allows us to hope that one day—beginning from tropisms, the most elementary reactions of living matter, and proceeding by way of conditioned reflexes and behaviour—we shall be able to analyse the mechanism of instinct and perhaps of intelligence itself. The latter, too long considered a perquisite of man alone, must now be attributed to many different species.

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The evolution of particle counters

H. GREINACHER

The ready availability of a wide range of radioactive isotopes, and of specific compounds containing them, has led to their extensive and fruitful application in many branches of science, medicine, and technology. Counting devices, necessary for assaying the rate of emission of particles, have in consequence become of general scientific importance. The evolution of counters and the principal characteristics of some present types are here reviewed.

Counting methods date from the discovery by E. Elster and H. Geitel in 1903, simultaneously with W. Crookes, that when α -particles strike zinc blende (ZnS) flashes of light are produced. This provided a very simple means for detecting and counting α -particles, which Rutherford used in the well known experiments that led to the formulation of the Rutherford-Bohr model of the atom. This scintillation method had, however, the disadvantage that the observations were very laborious, and that no permanent record was possible.

THE PROPORTIONAL (GAS MULTIPLICATION) COUNTER

A considerable step forward was made in 1908, when E. Rutherford and H. Geiger [1] found a method for detecting and counting α -particles by means of their ionizing action. This ionization effect was too small for direct measurement with the means then available, but they attained their objective by multiplying the number of ions formed by one particle by means of collision ionization. This was done with the device shown diagrammatically in figure 1. A wire of 0.5 mm diameter passes axially through a metal cylinder Z, and is connected at one side to a quadrant electrometer Q, and at the other to a radioactive resistor R. The tube, across which a P.D. of about 1000 volts is applied, is exhausted through the connection P until the pressure is reduced to a few centimetres

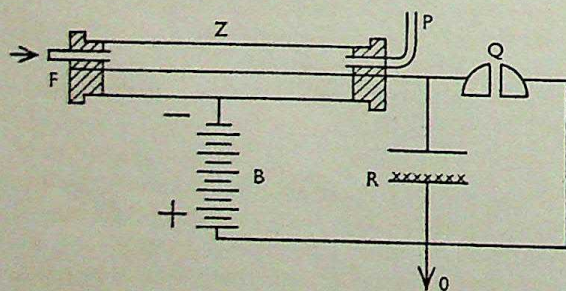


FIGURE 1 - Proportional counter.

of mercury. If an α -particle travels through the thin mica window at F, a current pulse passes. The electrometer shows a deflection, which rapidly vanishes because the electrical charge leaks away through the resistance.

The process in the tube is as follows. The α -particle ejects electrons from the gas molecules. These accelerate towards the wire as they enter an increasingly intense part of the electrical field. By collision with gas molecules they produce new electrons, which in turn produce more by collision, and so on. In this way an avalanche of electrons is produced, and the original ion charge is multiplied very greatly, becoming large enough to measure. The degree of multiplication increases with the applied voltage, but the voltage must not be too high or continuous discharge sets in. The duration of the discharge process is about 10^{-4} sec; the electrons themselves discharge in 10^{-6} sec, but, because of their lower velocity entailed by their much greater mass, the positive ions simultaneously present take longer to reach the wall of the tube. In spite of the rapidity of the discharge process, the inertia of the needle of the quadrant electrometer originally employed prevented more than 3-5 particles per minute being recorded. The proportional counter, in its original form, was at first little used; it found general application only with the introduction of 'counter tubes' twenty years later. Nowadays the method is among the fastest, and by it a million particles a second can be counted. An advantage is that the current pulse is proportional to the primary ionization. Thus α -particles can be counted independently of any β -particles, since these have about 100 times weaker ionizing power.

THE POINT COUNTER

At first interest turned in the direction of the point counter (figure 2) described by Geiger [2] in 1913, though this is now largely displaced by

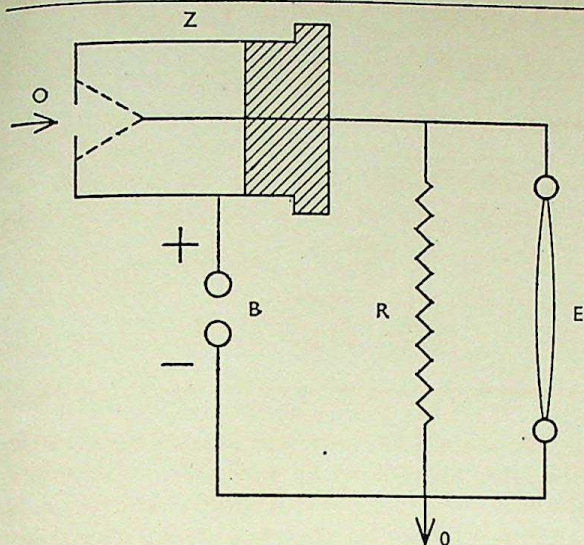


FIGURE 2 - Point counter.

the Geiger-Müller counter. A pointed wire projects into a small metal cylinder Z, and is connected with a rapidly responding string-electrometer E and a resistor R of 10^8 to 10^9 ohms. A voltage of 1000–2000 volts is applied to the cylinder; this is somewhat below the discharge potential. If a particle now passes through the window O, which is either open or covered with thin aluminium foil, discharge occurs momentarily from the point and the electrometer registers a pulse. The reason for the immediate interruption of a point discharge is to be found in the space-charge effect. It can easily be understood if it is imagined that a negative potential is applied to the cylinder. Then we have, as with a proportional counter, a slowly drifting positive ionic cloud following the rapid discharge of the electron avalanche. Until this cloud is discharged at the casing, it opposes the applied field, which thus cannot produce another discharge. Unlike the early proportional counter, this instrument responds to, and counts, α -, β -, and γ -particles. For demonstration purposes it suffices to fill it with air and to use an outgassed point, but for instrumental purposes the point is replaced by a small sphere (0.1–3 mm diameter), and many different gases are used. The sensitive volume, i.e. the space in which the particles are counted, is shown with dotted lines in figure 2. If the potential applied to the cylinder is increased, the pulse amplitude increases, but the pulse rate stays nearly constant. There is thus a so-called 'plateau,' the slope of which is given by the relative increase of pulse rate per 100 volts rise of applied voltage.

The time which must elapse between the passage of two successive particles if they are to be separately recorded depends on the course of the process in the interior of the counter, and on that in the external circuit. Complete counting evidently occurs only if the charge transferred has completely leaked away through R.

If the capacitance of the wire plus electrometer is C, the decay of the electrometer voltage is given by $V = V_0 e^{-t/CR}$. The potential thus falls to $1/e$ of its value in a time $\tau = CR$. The time constant τ thus determines the rapidity at which the charge leaks away, and therefore the resolution-time of the instrument; thus, if $C = 10$ picofarads and $R = 10^9$ ohms, it is $1/100$ th of a second. This does not necessarily mean that all the α -particles from a sample which on the average gives off 100 particles every second, will be counted. The emission of particles is not at all a regular event, so that some of them always escape counting because they come off too soon after the previous one. However, the proportion which thus escapes can be determined mathematically if the resolving power is known. Because of the statistical distribution of incoming particles, the mean particle-count per second can be determined with accuracy only if a sufficiently large number of particles is counted. The relative uncertainty in such a measurement is given by $\Delta z = 1/z^{1/2}$, where z is the number of particles counted. Hence the time constant must be as small as possible, in order to allow a high rate of counting. As the current pulse in the point counter is approximately 10^8 times the primary pulse, a mechanical counting device can be operated with the help of moderate valve amplification.

THE ELECTROMETER COUNTER

The charge liberated with strongly ionizing particles is so large that it can be detected with a sensitive electrometer; one α -particle from polonium, for example, produces about 200 000 ion-pairs. After K. W. F. Kohlrausch and E. v. Schweidler, in 1912, had observed the charge by jerks of a string electrometer by α -particles, G. Hoffmann [3] provided, in the same year, his Duantelectrometer. With this it was really possible to measure the ionization produced by single α -particles and protons. A general application of this method has, however, been hindered by the fact that it demands an intricate and costly instrument, and because only a few particles can be counted per minute, owing to the inherent inertia of the electrometer.

THE CHAMBER COUNTER

The problem of detecting particles directly through their primary ionization was meanwhile attacked from a different direction. Work with valve circuits in combination with the point counter [4] led the present author to the idea of avoiding the point discharge and of amplifying the primary ionization of the α -particles to such an extent that they could be directly recorded. It was actually possible, by using four amplifying valves, to obtain clicks from a loudspeaker [5]. Figure 3 shows, diagrammatically, the layout of this counter, which consists of a combination of a small ionization chamber with an amplifying valve of specially high grid-insulation (electrometer valve). If an α -particle enters through O, the electrode, and hence the grid, receive a minute charge; this alters the anode current of the valve. The pulse is next amplified by a linear amplifier, to enable it to operate a recording circuit. This amplification needs to be much higher than that for the proportional and point counters; it must be about 10^6 . The counter is correspondingly more sensitive to disturbance, and requires particular protection from vibration and noise. There is also always a certain background, arising from the statistical variations of the grid current. The resolution-time is very short, since the ions discharge rapidly in the strong field (10 000 volts/cm). As above, it is measured by the time constant CR , but this can be made very small.

With these counters, α -particles and protons can be recorded without interference from β - and γ -particles present at the same time. The first photographs of records made by such particles [5], obtained by means of an oscilloscope, are reproduced in figure 10. The new method was soon adopted in several laboratories, and Rutherford

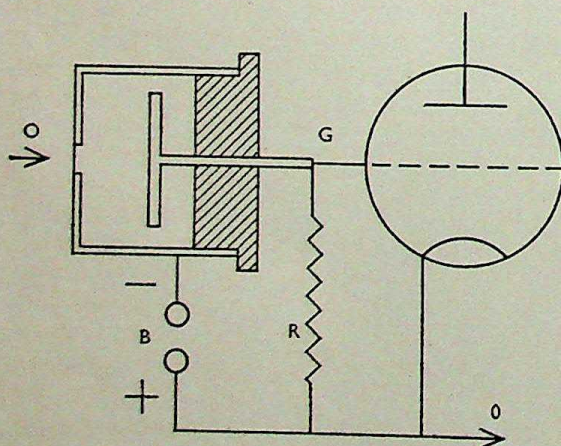


FIGURE 3 - Chamber counter.

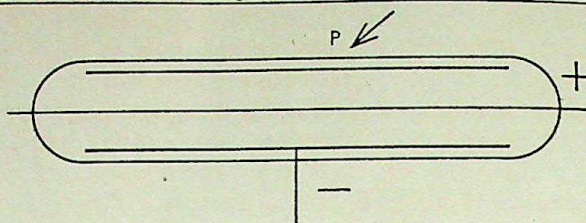


FIGURE 4 - Geiger-Müller counter.

and his collaborators published several papers on it; they called the instrument either a valve counter or a chamber counter. Unfortunately, the most diverse terms have since been applied to it, such as valve electrometer, Greinacher counter, ionization chamber with proportional amplifier, or simply proportional counter; the latter is an unfortunate term, since it had already been used for the multiplication counter. Rutherford's short and apposite name, chamber counter, is to be preferred.

The chamber counter has proved to be an indispensable adjunct to nuclear research. It can be used for the detection not only of α -particles and protons, but also of neutrons, which do not themselves produce ionization. If the chamber is filled with gaseous boron trifluoride, the B^{10} isotope may be transformed by collision with neutrons; this process is accompanied by emission of an α -particle, which is then counted. If fast neutrons have to be detected, a hydrogen-containing substance, such as polythene, is brought into the chamber; from such substances protons are ejected by recoil. The manufacture of high-efficiency chamber counter equipment is no longer a problem, and it may be bought ready for use.

THE GEIGER-MÜLLER COUNTER

Up to 1928 the point counter had to be used for the counting of β - and γ -rays. In that year H. Geiger and W. Müller [6] announced a considerably improved counter; the design (figure 4) is similar to that of the multiplication counter. The wire, however, is very thin, and the metal cylinder is sealed into a glass envelope. The counting process is similar to that in the point counter; instead of a point discharge, a corona discharge is obtained. The particle can enter at any point P, because the sensitive volume extends over practically the whole tube. While originally Geiger and Müller thought that counting could be done only if the wire is covered with a thin insulating film, H. Kniepkamp showed that the counter works even with bare wire. Usually a fine tungsten wire is used, which is baked to outgas and purify it.

For convenience in heating the tube, counters are made (following a suggestion made by R. Maze) without internal metal cathodes, but with an external conducting coating on the glass envelope. Commercial, and therefore not entirely pure, argon is generally used to fill the counters, at a pressure of about 80 cm of mercury. The negative voltage applied to the tube is about 1000 volts.

Since the corona discharge always forms along the whole of the wire, the amplitude of the pulses is always the same, regardless of whether strongly ionizing α -particles or very weakly ionizing mesons are measured. In the exceptional case of α -particles entering the tube at right angles, up to 50 times greater pulses are obtained (P. Huber and E. Baldinger, 1947).

A new stage in the development of the Geiger-Müller counter was reached with the discovery by A. Trost [7] that, by admixing with the argon gases whose molecules contain four or more atoms, 'self-quenching' counters can be made. In the usual counter a high leak-resistance has to be provided to ensure that even after discharge of the positive ions—that is to say, after the disappearance of the space-charge—the potential will fall to below the discharge potential. Such a resistance is not required with the self-quenching type. Here the discharge process is permanently interrupted even after the discharge of the electron avalanche, i.e. after about 10^{-6} sec; such counters are said to be 'fast.' The whole electrical process, however, including the drift of the positive ions, is in no way quicker than usual. However, the time constants of such counters can be reduced by using a smaller resistance R , and so the speed of recording can be increased. By suitable valve circuits, however, the same resolution can be attained even with ordinary counters. Many workers, such as E. Baldinger, P. Huber, S. A. Korff, C. G. and D. D. Montgomery, and H. G. Stever, have concerned themselves with the not altogether simple conditions existing in these counters, but only a few fundamentals can be discussed here.

Two separate phases in the counting process must be distinguished: the dead time, during which no second particle is indicated, and the recovery time, at the beginning of which the pulses are counted at low intensity and at the end of which they are counted again at full intensity. Both intervals are of the order of 10^{-4} sec. As E. Greiner showed for the first time, the photo-effect plays a decisive part in the discharge process. If an electron avalanche is formed at any point in

a counter filled with argon—and therefore not of the self-quenching type—it excites the argon atom itself to emission of ultra-violet radiation, which releases photo-electrons from the wall. In this way electron avalanches are initiated on all parts of the wire, until the latter is surrounded by a positive ionic sheath which screens the field. The discharge is then quenched, and the ions travel to the wall of the tube, from which they detach electrons, giving up their energy in the process. If at this stage the transferred charge has already leaked away through the resistance R these electrons now induce a second discharge. A permanent disruptive discharge would then arise; to quench it, the resistance must be sufficiently high. But if vapour such as that of alcohol is mixed with the argon, the ultra-violet radiation, even if it is emitted during the first electron avalanche, is absorbed by the vapour after traversing only a few millimetres of it, and does not reach the tube wall. This absorption is accompanied by the ejection of electrons from the vapour molecules in the immediate neighbourhood of the avalanche, since the vapour is more easily ionized than argon is. The discharge therefore spreads along the wire (at the rate of 10^6 to 10^7 cm/sec) and positive ions again drift to the wall, but now they consist almost entirely of ionized vapour molecules. As these are not able to detach electrons from the wall, no further discharge occurs, even if the applied voltage is fully effective. Instead, the vapour molecules decompose, and this decomposition sets a limit to the life of such self-quenching tubes; nevertheless, they will measure up to 10^8 and more pulses without trouble. According to E. Fünfer and H. Neuert, counters filled with a pure vapour such as that of methylal, $\text{CH}_2(\text{OCH}_3)_2$, show a good quenching action.

If a voltage below the 'Geiger-Müller threshold' is applied to such a counter, it operates as a proportional counter, and no ionic sheath is formed, nor are electrons liberated at the tube wall as a result of the positive ions arriving there.

Counters are commercially available in different patterns and sizes, down to less than 1 cm long and 2–3 mm diameter. Complete measuring equipments incorporating Geiger-Müller counters are manufactured, ranging from impressive laboratory instruments to compact control and ore-prospecting outfits. Figure 7 shows such a portable instrument. The counter is firmly clamped to the handle, and with it either γ -rays alone, or both γ - and β -rays, can be measured, according to the position of a rotatable diaphragm. Beside this apparatus

lies another counter, which counts α -particles if the cap is removed. The counting speed can be as high as 100 000 per minute.

COUNTING EQUIPMENT

The circuits into which Geiger-Müller counters are inserted come within the province of electronics and can be dealt with only briefly here. In general, the counter is connected with a coupling circuit, which executes a quenching action on 'slow' counters; to this are connected an amplifier and finally a recorder. As mechanical counters generally cannot cope with more than 500 pulses per second, scalars are employed, permitting far higher counting speeds at a resolution of 10^{-6} sec. In these devices a circuit is employed such that only every second pulse is recorded (hence the term 'scale of two'). If this pulse is fed to a second scalar, then only every fourth pulse is counted. If n scalars are connected in series, only one in every 2^n particles will be counted. The response of each stage in the cascade of scalars is indicated by a neon lamp. If, for instance, the lamps in circuits 1, 3, 4, 7, and 8 light up, the corresponding number of pulses is $1 + 8 + 16 + 128 + 256 = 409$. Scalars working on a scale of ten have also been made.

If the number of particles per second is to be determined, a determination of time is evidently involved; this can be avoided by employing an instrument known as a rate-meter (figure 7). A large-capacitance condenser is included in the recording circuit of the counter, connected across a current-measuring instrument. This indicates the electrical current carried by the output signal.

If it is desired to count only the pulses which exceed a certain magnitude, a discriminator is employed. This is, in principle, a valve whose grid is made so negative that only positive signals of a certain magnitude can pass the barrier. By using a number of such discriminators, which count either pulses of different magnitude or different pulse intervals—for example, by sorting the pulses according to size—the pulse distribution can be determined (pulse spectrometer).

Many problems of nuclear physics require a decision as to whether two or more events are simultaneous. To solve this there are 'coincidence' circuits. W. Bothe was responsible for the first, though that developed by B. Rossi is much used nowadays. With the aid of delayed coincidences, intervals of time between two events down to 10^{-9} sec can be detected. If a pulse-reversal stage is inserted into the circuit, an 'anti-coincidence' cir-

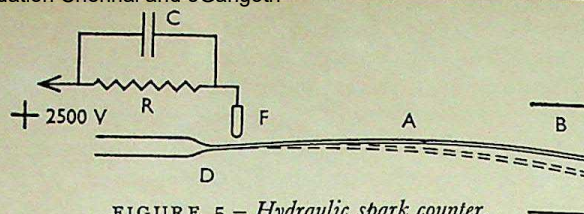


FIGURE 5—Hydraulic spark counter.

cuit is obtained, which indicates when one event occurs independently of another.

THE SPARK COUNTER

The first spark counter, which was described by the present writer in 1934 [8], was the hydraulic model. Figure 5 shows one suitable for a demonstration experiment. A jet of water about 1 mm thick, and coherent for about 20 cm, flows out through the nozzle D. An iron rod F is set about 1 mm away. A positive voltage of about 2500 volts is applied to it, such that there is no spontaneous spark discharge. The resistance is about 10^8 to 10^9 ohms and the capacitance about 100 picofarads. Any spark released by α - or β -particles or γ -rays causes a drop in the potential of F. The attraction on the water jet decreases for a moment, so that the jet executes a jerky movement, giving rise to a sharp sound from the metal can B. If we imagine a recording instrument to take records of the point A of the water jet, photographs such as that shown in figure 11 would be obtained. Sparks are produced by ultra-violet radiation as well as by α - and β -particles and γ -rays; for this purpose electrons released photo-electrically from water suffice. The hydraulic spark counter is a quite general means of measuring the elementary photo-effect on the surfaces of pure liquids.

In the usual spark counter [9] there are two metal electrodes, which can be of the most diverse

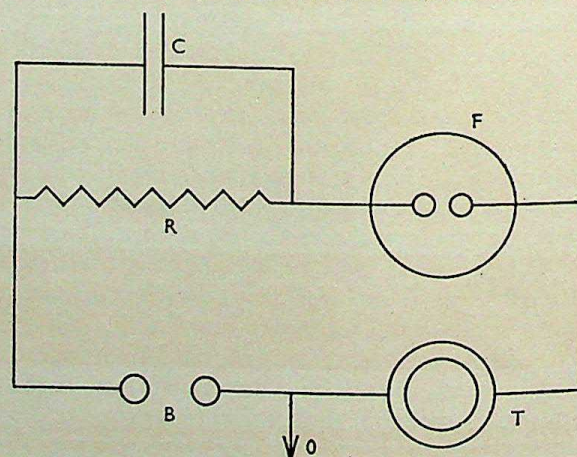


FIGURE 6—Spark counter based on combination of two spheres.

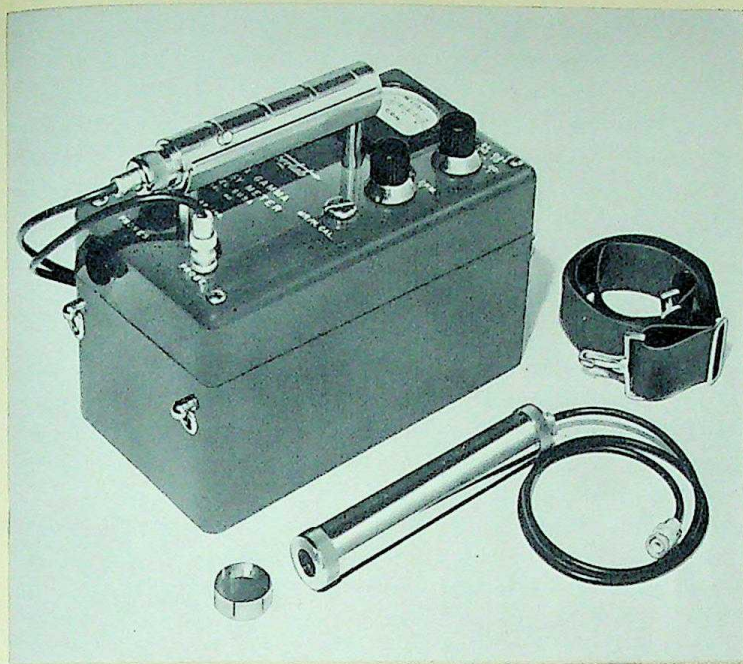


FIGURE 7 — Geiger counting instrument (rate-meter).

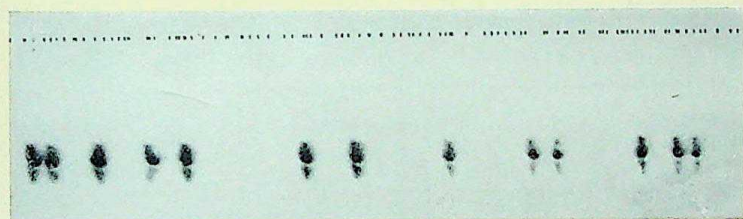


FIGURE 8 — Spark sequence; lower series magnified.

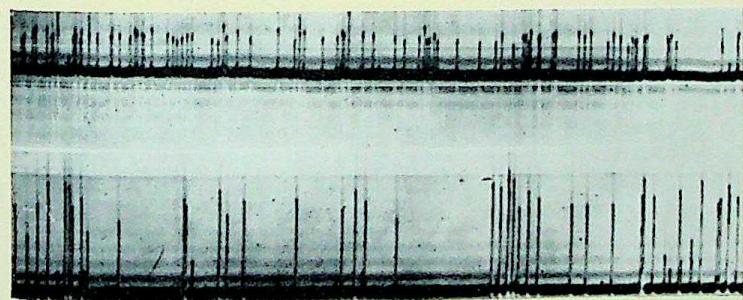
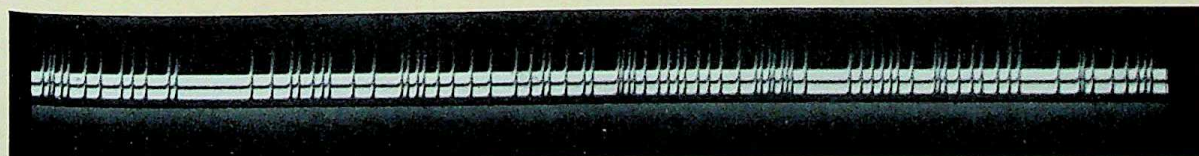
FIGURE 10 — The first recording made with a chamber counter. Above, protons; below, α -particles.

FIGURE 11 — Recording made with an hydraulic spark counter.

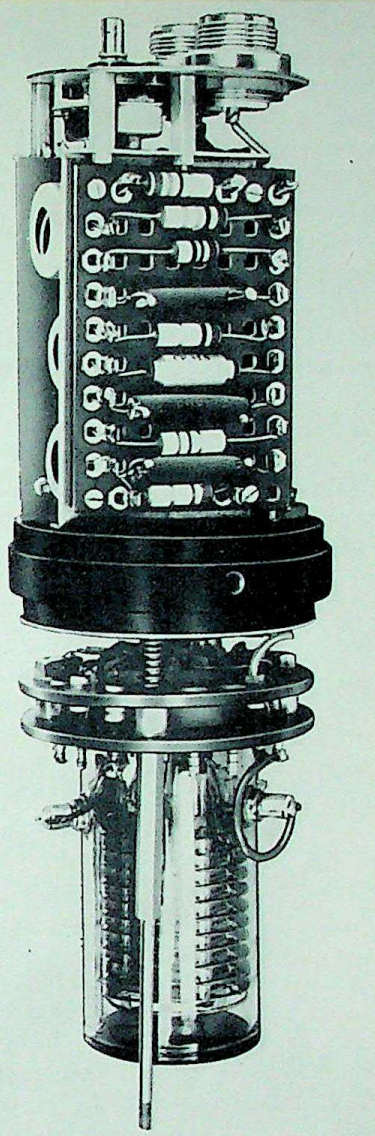


FIGURE 9 — Scintillation counter (interior): assembly of crystal, multiplier, and amplifier. Above, amplifier; below, multiplier with crystal.

NOTE. Figures 7 and 9 have been supplied by Messrs Tracerlab, Boston, U.S.A., and Ekco Electronics Limited, Southend-on-Sea, respectively.

forms, set about 1 mm apart. Figure 6 shows a combination of two spheres. The current pulses obtained here are so large that they can be detected directly with a galvanometer, neon tube, or loud-speaker. Usually no indicator is inserted into the circuit; either the spark is photographed (figure 8 shows a record so obtained) or the waves propagated from the sparks are picked up by a radio receiver. Audible spark cracks are obtainable if the electrodes are set at larger distances.

It is interesting that below the voltage necessary for counting β - and γ -rays there is a further range—some 100–200 volts—where only α -particles are counted. In the upper region all particles produce pulses of equal magnitude, whatever the primary ionization. This indicates the same discharge mechanism in all cases: collision ionization by the primary electrons and release of electrons from the cathode by the resulting ultra-violet radiation and by secondary emission on impact of positive ions. There are, however, still unsolved problems relative to the spark process. For example, sparks can be released even without irradiation. It is sufficient, for instance, to bring a piece of camphor into the neighbourhood of a spark gap, ready for flash-over, for a spark sequence to occur; this dies away when the camphor is removed.

Since the duration of a spark is brief (as little as 10^{-9} sec), the spark counter has been further developed as the plate counter [10]. Two metal plates are set 1–2 mm apart in a glass vessel, filled with argon-alcohol at about half an atmosphere pressure, as in the Geiger-Müller counter. Unlike the normal spark counter, it gives a plateau. The sensitive volume, extending over the whole intermediate space, is also considerably larger.

W. Y. Chang and S. Rosenblum [11] have reported an interesting method of operating the spark counter. The arrangement consists of a thin wire, stretched at a height of about 1–2 mm

above a metal plate. A positive potential of about 3000–5000 volts is applied to it, high enough for a continuous corona current of about 1 milliamp to flow. If an α -particle passes the wire, a directly visible and audible spark is produced. To enlarge the counting volume, counters have been made with many parallel wires in 'guitar and harp' forms. The corona spark counter, which does not respond to β -particles or γ -rays, is the only such instrument which operates with a steady current.

THE ELECTRON MULTIPLIER

The counters so far described have the common feature of being based on gas ionization. This is not so with some newer methods, which are based on electron multipliers. Figure 12 shows the essentials of such a device. A number of metal electrodes are sealed into an evacuated glass envelope. A potential of 1000 volts or more is applied between the first and the last electrodes, and this potential is divided between the various electrodes so that there is always the same difference—say 100–200 volts—between two successive electrodes. Electrode 1 has a photo-electric coating such as caesium oxide. Electrons released by incident light are accelerated to electrode 2, from which they release secondary electrons, which travel to electrode 3, and there again multiply themselves by secondary emission. There is thus a progressive multiplication. If the multiplication is threefold between any two electrodes, and there are altogether 13, the total multiplication is 3^{12} ; with 16 electrodes a factor of 10^9 can be reached.

The principle of the electron multiplier was published as far back as 1923 by I. Slepian. However, it was not until 1936 that V. K. Zworykin [12] brought it, by good focusing of the electron beam, to the efficiency necessary for technical use. The multiplier, originally developed for television, thus became available as a perfected instrument for nuclear physics. Reports on the measurement of α - and β -particles and γ -rays with multipliers, with and without photo-electric layers, appeared as early as 1938–9 [13]. The resolution of these counters is 10^{-8} sec, higher than with Geiger-Müller counters because the process occurs in a vacuum. Nevertheless, the new method did not at first find very wide use.

SCINTILLATION COUNTERS

In 1947 H. Kallmann proved [14] that the flashes of light produced when α -particles strike zinc blende can be recorded with a photo-multiplier. A scintillation counter based on this

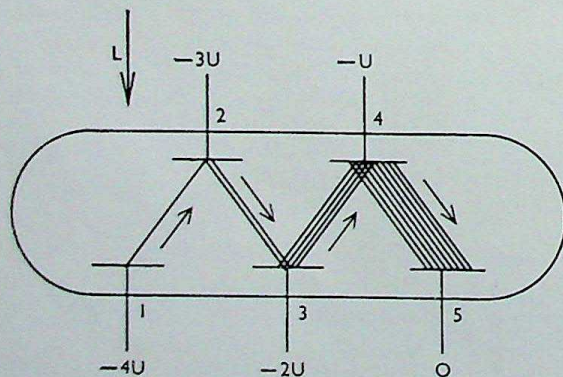


FIGURE 12—Principle of the electron multiplier.

principle consists of a multiplier, before whose input plate a crystal is placed. Even the scarcely visible flashes from β - and γ -rays can be counted. The crystal used must give out a considerable flash, and the flash must decay rapidly; in commercial scintillation counters a sodium iodide crystal activated with thallium is used. In this way an efficiency for Röntgen and γ -rays considerably above that of Geiger-Müller counters can be attained. Anthracene is also suitable as material for the crystal, because of its small decay time; stilbene gives even shorter light flashes (10^{-8} sec and less). Liquids too are used.

These counters must be carefully screened from light. Even then there is a residual background of natural signals, mainly because of thermal emission from the photo-cathode. This can be reduced by cooling, or, better, by using for the electrodes a material for which the work function is high, for example nickel with a thin covering of beryllium.

The non-homogeneity of the pulses is countered by insertion of a discriminator, which suppresses small pulses. Because of the high resolving power of the scintillation counter (down to 10^{-9} sec) it is of importance for timing nuclear processes. Electrostatically focused multipliers must be protected from magnetic effects, and it is therefore often desirable to separate the multiplier from the crystal. This can be very simply done by interposition of a light-guide (for example of Perspex) which transports the light by total internal reflection. If desired, the counting head can be provided with a lead hood or collimator, with a channel-shaped opening. For medical and biological purposes there already exist compact assemblies which contain an amplifier in addition to crystal and multiplier, and which can be directly connected to a scaler; figure 9 shows an example of such a set-up.

THE CRYSTAL COUNTER

Many crystals have the property of displaying an enhanced conductivity when particles are incident upon them. If such a crystal is brought between two metallic sheets to which a potential difference is applied, current pulses are produced by α - and β -particles and by γ -rays, and these can be recorded after even moderate amplification. P. J. van Heerden [15] has investigated this phenomenon, known since 1941, and has used a silver chloride crystal as a basis for a crystal counter. These counters are slightly older than the scintillation counters, but have not been able to command the same attention, although their resolving power is just as good. There is no lack of crystals—for example, diamond, cadmium sulphide, thallium bromide, germanium—but some complications are encountered in using them. Many crystals, such as silver chloride, must first be made insulating, which is done by cooling. Different counters of the same design show different counting action, and this action can even differ from place to place on the same crystal. The pulses are correspondingly non-homogeneous. This is related to the fact that electronic conduction is influenced by crystal lattice defects, which are irregularly distributed. Finally, interference is caused by polarization effects.

THE LIQUID COUNTER

Liquids also can show conductivity effects, but observations on this phenomenon are as yet very few. N. Davidson and A. E. Larsh [16] reported in 1948 that when liquid argon is used, counting pulses are obtained from α -particles. However, in the state of development they have at present reached, such counters cannot be said to be of any practical importance.

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Toxins and plant diseases

E. GÄUMANN

The micro-organisms responsible for disease act by virtue of the toxins they produce. Although the fundamental importance of this principle is recognized in medicine, and although there has been considerable study of the toxins produced by pathogenic bacteria, its implications in plant pathology are only beginning to be appreciated. Nevertheless, progress has been made towards identifying the toxins responsible for a variety of plant diseases. From such knowledge may come novel methods of treating infected crops.

Micro-organisms are pathogenic only if they are toxigenic; in other words, the agents responsible for diseases can damage their hosts only if they form toxins—microbial poisons—that penetrate into the host's tissues. This rather sweeping statement applies to both human and veterinary medicine, and to plant pathology. Hence in both fields an important question of pathogenesis is that concerning the physical action of the parasite on the host. What are the chemical nature and the mode of action of the substances secreted by the infective organism into the host, causing the latter to become diseased?

The extent to which such a question can be answered differs greatly in the medical and the plant pathological fields. Botanically, study of the problem of the genesis of disease is still new; up to the present, therefore, research has been directed to the acute provokers of disease which kill the tissues of their hosts. The biologically far more interesting groups of infective agents—those which do not damage their hosts in such a crude way, but only upset the normal tenor of their existence and stimulate them to greater neoplastic growth—have not so far been studied.

An interesting example of research in these more difficult fields is given by the tumours (crown galls) which are produced in many plants by *Bacterium tumefaciens* (figure 10). It is known that the development of these galls occurs in two stages: an alterative phase and a period of neoplastic growth. During the alterative phase the host-cells attacked by the irritant are set free from their internal connections and converted into potential tumour cells. These are not independently able to develop further as actual tumour cells; this can occur only in a second stage, in which the concentration of growth-promoting substance present in them increases. The additional quantity of growth-promoting substance is not, however, contributed by the parasite itself;

the latter induces the production of growth-promoting substance by the host.

Thus at least two toxins must be effective during pathogenesis of *B. tumefaciens* tumours: an alterative toxin, which causes the fully grown vegetative cells to become potential tumour cells, and a second toxin, which stimulates the host to abnormal production of growth-factor and thereby to neoplastic growth. The alterative toxin is of exceptional biological interest, as it is possibly comparable, *mutatis mutandis*, with carcinogenic substances in human pathology.

Both toxins, or groups of toxins, have so far escaped identification. The relevant alterative processes are biologically so subtle that it has not yet been possible to reveal them by a simple test, such as is necessary for routine assays in the chemical isolation of a substance. On account of these technical difficulties, research workers in botany have so far obtained results only with parasites which cause in the host more or less lethal damage, such as local necrosis. Results may be discussed under two headings: toxigenic parasites having respectively (a) short-range and (b) long-range action.

TOXIGENIC PARASITES WITH SHORT-RANGE ACTION

In parasites of this first group the toxins operate directly on the tissue surrounding the focus of infection. Not only the parasite but also the toxin it produces and the damage done are localized; the site of disease coincides very largely with the site of infection.

In medicine this type of disease is rare. One of the few examples (apart from certain skin diseases) is provided by *Clostridium histolyticum*, a wound parasite which causes necrosis at its point of attack, and dissolves the tissue down to the skeleton. In plants, on the other hand, numerous diseases are of this type—for example, many 'leaf-spot'

diseases. Two examples will be described here, the wildfire disease of tobacco and the early blight (dry-spot disease) of potatoes.

Wildfire in tobacco is caused by a bacterium, *Pseudomonas tabaci*, and gets its name from the characteristics of its incidence. It appears suddenly, and spreads rapidly through the whole crop; in some cases the harvest can be totally ruined. In rainy weather the bacteria penetrate through the openings of stomatal fissures into the interiors of leaves. After a few days the focus is necrotic and brown, and is surrounded by a bright green, chlorotic halo 1–2 cm wide (similar to that shown in figure 11), in which the chlorophyll suffers serious damage. This areola is free from bacteria; it is caused by traces of a substance called tabtoxinin, formed by the parasite in the central focus of infection, from which it diffuses into the surrounding tissue. Chemically, tabtoxinin is an α -amino acid, a diamino-hydroxypimelic acid having the formula $C_7H_{14}O_5N_2$ [1]; closely related compounds are produced also by the bacteria that cause diphtheria and tuberculosis. Tabtoxinin is extraordinarily poisonous to the tissue of tobacco leaves and even 0.05 μ g produces necrosis, surrounded by a chlorotic halo (figure 11).

To work out the mode of action of this toxin, Braun [2] used as a test organism the unicellular green alga *Chlorella vulgaris*. The rate of growth of *Chlorella* cultures is reduced by *Pseudomonas* toxin. If liver extract is added to such retarded cultures, tabtoxinin is not deactivated, but its retarding effect is eliminated; thus the liver extract apparently contains some factor, essential for *Chlorella*, that is rendered inaccessible by the tabtoxinin.

It was finally recognized that *l*-methionine is the factor which suppresses the toxic action of wildfire bacteria. The decisive part of the action of tabtoxinin consists in preventing *Chlorella* from using *l*-methionine that it has itself synthesized. This explanation is supported by the fact that a synthetic antagonist of methionine, methionine sulphoximine, causes the same symptoms in tobacco leaves as does *Pseudomonas* toxin.

Tabtoxinin is non-specific both in its host-range, for it affects various plants, and in the tissues it attacks, for it damages various tissues of the tobacco plant. On the other hand, it is highly specific in its point of attack inside the host cells, for there it blocks a clearly defined link in the metabolic chain.

Dry-spot disease (early blight) of the leaves of

various Solanaceae, such as potatoes and tobacco (figure 1), is caused by the fungus *Alternaria solani* (figure 9). The host's tissue reacts to the diffusion of the metabolic products of this fungus, forming darkly coloured, suberized barrier-tissues. In circumstances favourable to the fungus these barrier zones are, however, again pierced by the parasite, so that in time there forms round the focus a whole series of concentric barriers of suberized defensive tissue (figure 8).

The aetiology of this disease is much more complicated than that of wildfire, as can be seen by considering figures 8 and 11. In wildfire there is a simple tissue-poisoning, whereas with early blight there is a complicated and obscure interplay of actions and reactions. Since the host is the same in both cases, the different reactions must be determined by differences in the nature of the parasite.

Alternaria solani forms several toxins, of which two have so far been isolated: alternaric acid [3] and alternarin [4]. Both are nitrogen-free substances, and their chemical constitutions are still unknown. The formula of alternaric acid is $C_{21}H_{30}O_8$ and its molecular weight 410.

The nature of the action of these two toxins on the host, and the nature of their interaction in the host, are not known. They are apparently even less specific in their action than tabtoxinin is. While the latter attacks at one point in the metabolic chain, alternaric acid, for instance, is capable of upsetting several metabolic mechanisms in the host; for example, it interferes very seriously with the osmotic properties of the host cells. Corresponding to this smaller specificity, alternaric acid is less toxic than tabtoxinin; nevertheless, it produces fatal effects at a dose-rate of 220 μ g per kg of live-weight of the host [5].

These two leaf-spot diseases cause only local necroses in the host, and, in contrast to *Clostridium histolyticum*, quoted above, do not lead to any histolysis such as is known in some other plant diseases, e.g. certain infections of trees. Figures 6 and 7 show two samples of wood from the trunk of an oak suffering from a fungal disease. The causative agent, *Stereum frustulosum*, has penetrated into the interior of the trunk through wounds and has dissolved out the protopectin and lignin from the woody tissues, leaving the cellulose untouched. The white parts in figure 6 and the white fibres in figure 7 are thus not threads of fungus, but woody fibres, freed from their surroundings by the lytic enzymes of the parasite so that the white cellulose is revealed like purified cotton wool. The

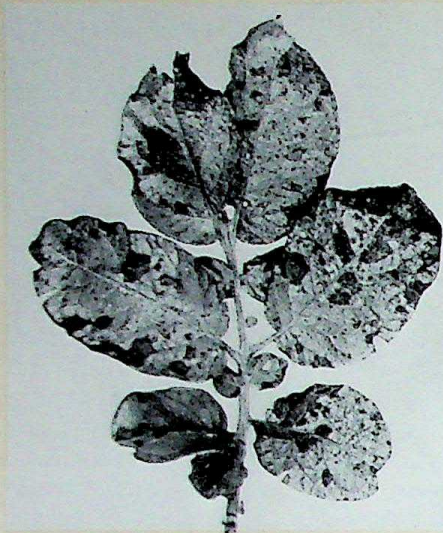


FIGURE 1 - Early blight of potato leaf, caused by the fungus *Alternaria solani*. (After R. Maag.) ($\times \frac{1}{2}$)

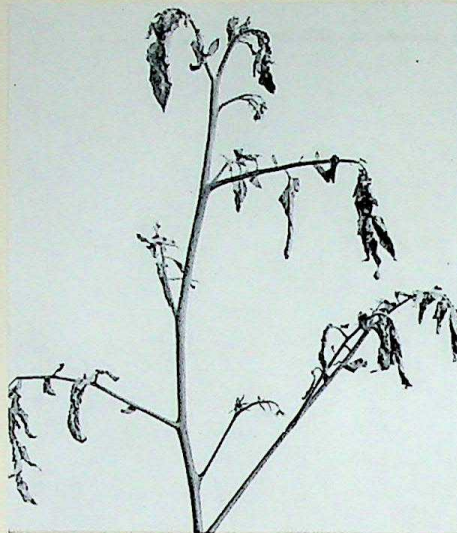


FIGURE 2 - Wilt breakdown of a tomato plant under the influence of lycoramin. The leaves are withered, but the petioles and stems are still turgid. ($\times \frac{1}{5}$)

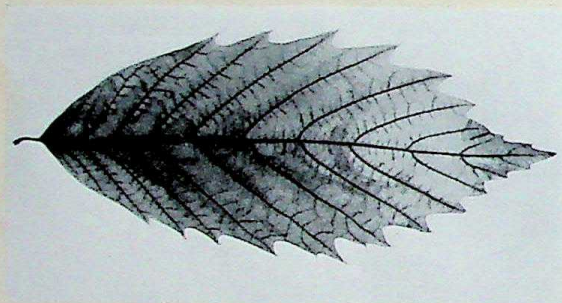


FIGURE 3 - Necrosis of the vascular bundles of the leaves of Spanish chestnut (*Castanea sativa*), caused by the wilt toxin diaporthin, a product of *Endothia parasitica*. ($\times \frac{1}{3}$)

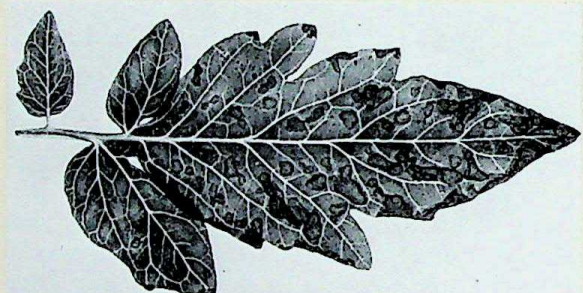


FIGURE 4 - Illustration of the principal damage to tomato leaves by lycoramin; note necroses of the intercostal regions, the leaf veins remaining unattacked [14]. ($\times \frac{3}{4}$)



FIGURE 5 - Main symptoms of patulin wilt: the stems and petioles of tomato plants lose their turgor, while the leaf blades at first remain intact. ($\times \frac{1}{4}$)



FIGURE 6 – Early stage in an infectious disease of the trunk of an oak, caused by the fungus *Stereum frustulosum*. Characteristic cavities have been formed in the woody tissue. (Natural size)

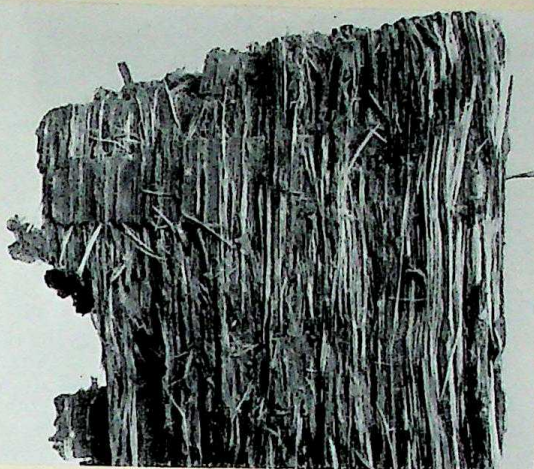


FIGURE 7 – Late stage in the infectious disease of an oak trunk, caused by *Stereum frustulosum*. Histolysis has caused complete defibrination of the woody tissue. (Natural size)



FIGURE 8 – Detail of early blight on a potato leaf, caused by *Alternaria solani*. The focus of infection is surrounded by concentric, suberized, anti-toxic demarcation zones. (After R. Maag.) ($\times 10$)

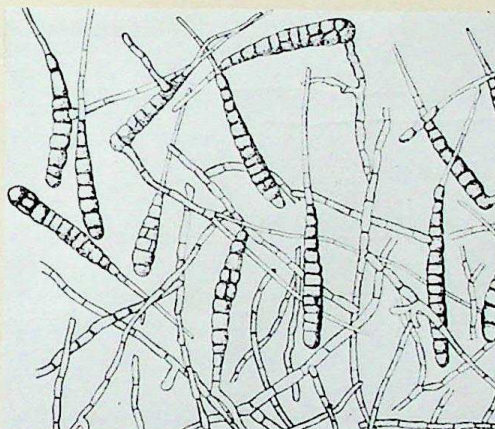


FIGURE 9 – Conidia of *Alternaria solani*, the cause of early blight on the leaves of tobacco and potato plants [4]. ($\times 160$)



FIGURE 10 – Tumour with root formation on a stalk of *Impatiens balsamina*, produced by *Bacterium tumefaciens* [13]. ($\times \frac{1}{2}$)

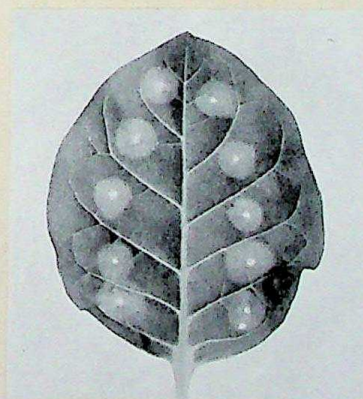


FIGURE 11 – Chlorotic damage produced in a tobacco leaf by traces of tab-toxinin. (After A. C. Braun.) ($\times \frac{1}{5}$)

parasite thus produces in the woody tissues first the characteristic cavities of figure 6 and finally the general breakdown of tissue shown in figure 7.

TOXIGENIC PARASITES WITH LONG-RANGE ACTION

In medicine, tetanus is the standard example of this second group: the pathogenic bacterium develops anaerobically in a peripheral wound and its toxin penetrates into the host tissue, diffusing along the nerve tracks to the brain and there producing the characteristic paralysis of the motor system. The site of the disease and the appearance of symptoms are thus remote from the focus, and the generic connection between these two elements of the disease was recognized only after decades of scientific research.

In the vegetable world, infectious diseases in which there is separation of the site of infection and the area in which the symptoms appear are represented by a series of economically important 'wilt' diseases. Thus *Fusarium cubense* causes, throughout the tropics, the Panama disease of bananas; *Fusarium vasinfectum* is a wilt disease of cotton plants in most regions where they are cultivated; and *Endothia parasitica* is responsible for the death of many chestnut trees in the northern hemisphere.

In all these diseases, the parasite attacks a particular site—for example, the roots or shoots or stems of the host—and transmits its toxins into the host's vascular system. The toxins are transported into the foliage and, in certain circumstances, may cause such a surprising collapse of the leaves that the corresponding disease of apricot trees in the valley of the Rhône has been dubbed 'apoplexy.' Apricot trees infected with a fungus of the *Valsa* group, not noticeable on the trunk, appear normal in the spring and bloom in the ordinary way. In June their crowns lose their turgor almost overnight through the action of the toxin, they wilt, and whole trees perish.

The study of these wilt diseases was begun on an economically less important representative, namely the wilt disease of tomatoes, caused by the fungus *Fusarium lycopersici*. The reason for this choice was that tomato plants can be easily cultivated throughout the year, in large numbers, in a glasshouse.

The parasite penetrates from the soil into the roots of the plants and grows far up into the stems. Its toxins cause a browning and necrosis of the vascular bundles of the stem (similar to the symptoms in leaves seen in figure 3) and characteristic

discoloration and necrosis of the leaves (figure 4).

Up to the present, four toxins have been isolated from *Fusarium lycopersici* grown *in vitro*. Two of these (pectase and vasinfuscarin) specifically produce the browning and necroses of the vascular bundles, and two others (lycomarasmin and fusaric acid) are mainly responsible for discoloration and necroses of foliage.

Pectase [6] is a pectin methyl esterase, produced by numerous parasitic fungi. Vasinfuscarin [7] is apparently a protein having enzymatic properties, but it has still not been isolated in the pure state. Lycomarasmin is a dipeptide having the formula $C_9H_{15}O_7N_3$ and molecular weight 277 [7]. Fusaric acid is a pyridine carboxylic acid with the formula $C_{10}H_{13}O_2N$ and molecular weight 179 [8].

Chemically, these four toxins belong to different groups. Their molecular weights are small compared with bacterial toxins well known in medicine (diphtheria toxin has molecular weight 72 000; botulinus toxin A, 900 000). This may be connected with the selective filter-action of the cell walls of plants. Solutions which rise into the plant shoots through the vascular bundles diffuse, after leaving these paths, within the cell walls and bathe the cell contents in the tissues from all sides. Hence the toxins, transported along with other dissolved substances, also bathe the protoplasts over their entire surfaces. Naturally, the toxins most active in the plant tissues are those which are capable of penetrating the submicroscopic spaces in the micellar felt of the cellulose walls; this means, in effect, toxins of relatively low molecular weight.

So far as present experience shows, human pathogenic bacteria exhibit a considerable specificity in respect of the toxins which can be extracted from them; thus tetanus toxin appears to be characteristic of the tetanus organism, diphtheria toxin of diphtheria bacteria, and so on. The active agents of plant wilt diseases are more primitive in this respect; that is, they are less specialized. Thus the fusaric acid mentioned above is produced not only by *Fusarium lycopersici*, but also by *Fusarium heterosporum*, which causes a disease in maize, rice, and sugar cane in eastern Asia; by *Gibberella fujikuroi*, the cause of the bakanae disease of rice in eastern Asia; by *Fusarium vasinfectum*, the cause of a wilt disease of cotton; and also by *Nectria cinnabarina*, the cause of red-spot disease in numerous shrubs and deciduous trees of the temperate zone. This substance is thus produced by various parasites on various hosts. This generality of toxin production suggests

that the toxins in question are produced by relatively simple reactions from widely occurring substances.

The wilt toxins do not act only on the specific host of the parasite that forms them. The range of plants sensitive to a particular toxin is considerably wider than the range of hosts of the toxin-producing parasite. Thus *Fusarium lycopersici* cannot attack the grape-vine (*Vitis vinifera*), but its toxins can produce the same sort of damage in the grape-vine as they do in the tomato. The natural resistance of the grape-vine to this parasite is thus not a reflection of any resistance to the toxin produced by it, but of a resistance to the parasite itself, which is unable to get a hold on this uncongenial host.

Do wilt toxins affect all tissues of the host uniformly? The answer is again in the negative. In plant wilt diseases, as in the human disease diphtheria, not only the sites of infection but also the organs attacked by the toxin or toxins are relatively specific. Wilt toxins act only on certain tissues of the host; they show a predilection for them—they are histotropic. Thus lycomarasin passes through the stems, petioles, and leaf veins of tomato plants almost without causing any symptom; it produces its primary symptoms only in the intercostal fields of the leaves (the regions between the leaf veins, figure 4). On the other hand, vasin-fuscarin damages only the vascular bundles of tomato plants (similar to that of the leaf veins in figure 3), leaving the tissues of the intercostal region intact.

The same predilection for certain tissues of the host is shown, however, by completely different toxins with an apparently completely different mode of action. Thus visually identical browning and necroses of the vascular bundles are produced by pectase, vasin-fuscarin, fusaric acid at pH below 6.2, and by diaporthin, a toxin of *Endothia parasitica* [9]. Hence, in plant wilt diseases identity of the outwardly visible symptoms in a particular organ does not necessarily indicate identity of the causal toxins.

Compared with the short-range toxins mentioned earlier (tabtoxinin, alternaric acid), the wilt toxins so far known are only mildly poisonous; a dose of 150 mg of lycomarasin or fusaric acid is required per kg of live-weight to produce definite damage to tomato shoots. The cause of this high threshold value is still unknown; possibly it is due to diffusional losses

resulting from adsorption or inactivation during transport, or something of the sort.

As mentioned earlier, all agents causing wilt diseases form several toxins, and each of these interferes, so far as we know at present, with several mechanisms in the host. The mode of action of the wilt toxins is thus less specific than that of the tabtoxinin previously described. The combined action of wilt toxins in the host is determined, however, not only by their chemical effects, but by the sequence and extent of their production by the parasite. We still know little about any of these factors.

The main symptom of the wilt diseases is the visible wilting, which makes the attacked plant become flabby. It was at first supposed that this was connected with a pathological loss of water from the attacked plant, similar to the physiological wilting which follows on a pathological deficiency of water.

However, this simple interpretation has not withstood tests made with individual toxins, for, depending on the toxin investigated, either the stems and petioles (figure 5, toxin patulin) or mainly the leaf blades (figure 2, toxin lycomarasin) are affected. Thus the impairment of the turgor is specific for certain organs and varies according to the particular toxin involved, and is not the result of simple water deficiency.

Moreover, although the wilt process may be accompanied by a pathological water-loss, this is not necessarily so. Pathological water-loss is thus only an accompanying symptom. If a tomato plant is allowed to take up a wilt toxin in an atmosphere of 94 per cent relative humidity its transpiration is at a minimum on account of the

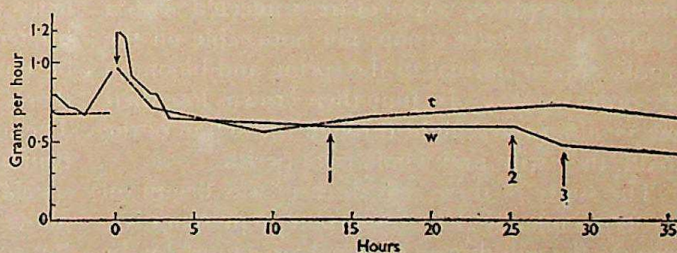


FIGURE 12—Graphs illustrating wilt of a tomato plant produced by toxin without loss of water. This occurs if the wilt test is carried out in an atmosphere almost saturated with water vapour. The experimental plant shoot was inserted into the toxin solution at the time marked with the arrow. The abscissae indicate the hours from the start of the experiment; the ordinates indicate water uptake (w) or transpiration (t) of the whole plant shoot in grams per hour. At (1) the leaves are no longer completely turgid, but slightly curled up. At (2) the growing tip is hanging down and the two lowest leaves are flabby and hanging from the petiole. At (3) all leaves are flabby and show considerable wilt [10].

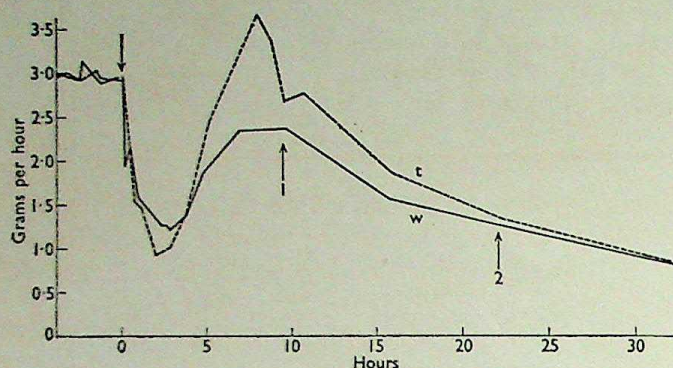


FIGURE 13 - Disturbance of the water balance of a tomato plant as a result of lycoramin; atmospheric humidity normal. Details as for figure 12. At (1) the lowest leaf shows the first signs of wilt. At (2) the whole plant has wilted [11].

high humidity (figure 12); nevertheless, it begins to wilt after 14 hours [10], and after 30 hours it is completely flabby.

There is a similar independence of wilt effect and water loss at normal humidities. Figure 13 illustrates the behaviour of some experimental plants which have responded to the application of lycoramin by very suddenly reducing, and then by exceeding, their normal water balance. About 10 hours after the beginning of the experiment the first signs of wilt appear, although at this time the tomato plants have lost only about 6 per cent of their water store. Sound plants can tolerate a water loss of about 50 per cent without visible symptoms. The wilt effect is thus not a matter of a pathological loss of water from the damaged plant, but of an interference with the directional permeability (semi-permeability) of its protoplasts, and thus of an interference with

the osmotic requirements necessary for turgor.

The mechanisms which lead to such impairment of the semi-permeability of the plasma membranes are still unknown. Several wilt toxins, including lycoramin and fusaric acid, can form chelate compounds with, and thus block, metal ions in the host that are essential to life: they can thus act as antimetabolites [12]. However, the relationship of this process to disturbances in permeability are still uncertain.

Moreover, the fungi causing wilt diseases form—together with the true wilt toxins, which produce the visual wilt of the attacked plants—still other toxins, which produce, for instance, local chlorosis (damage to chlorophyll), stiffenings (rigidification of certain organs), necroses, and so on, all symptoms that are superimposed on the visible wilt. We are therefore a long way from a thorough understanding of the pathogenesis of wilt diseases.

THE THERAPY OF INFECTIOUS DISEASES OF PLANTS

Knowledge of the nature of toxins produced by parasites opens up new possibilities for combating the corresponding infectious diseases. It is possible that eventually plant diseases may be dealt with not by attacking the parasite itself, but by inactivating its toxins by allowing the attacked plant to take up substances which would render them harmless; this is already the pattern of medical treatment for diphtheria.

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H. J. H. Fenton (1854-1929):

a great teacher

W. H. MILLS

The difficulty now being experienced, in many parts of the world, in recruiting scientific teaching staff, is a reminder of the vital role of the teacher in furthering the progress of science. This sketch of Henry Fenton, published on the centenary of his birth, illustrates how far-reaching can be the influence of an inspiring preceptor. It illustrates, too, that the teaching of science can be far more than the mere distillation of accumulated knowledge; Fenton, like many others, found much inspiration for original research in the work of his students.

There are great chemists and great teachers of chemistry, and the two distinct abilities are seldom found combined in a superlative degree in any one man. When they are not so found, it is normally the great chemist rather than the great teacher who acquires fame, and perhaps it is both inevitable and just that this should be so. Nevertheless, the healthy growth of a science needs inspiring preceptors no less than brilliant pioneers, for inspired teaching will germinate many a dormant seed of talent and give budding genius a propitious atmosphere for blossoming. One outstanding teacher, to whom generations of chemists look back with gratitude and admiration, was Henry John Horstman Fenton, born in London just a hundred years ago.

Fenton was educated at Magdalen College School, Oxford, and afterwards at King's College, London, where Bloxam was then professor of chemistry. At that time, one of the City Companies—merchant guilds of which some were established in London as early as the eleventh to thirteenth centuries—offered an exhibition in physical science tenable for three years by a non-collegiate student at Cambridge. It was won by Fenton, and in accordance with its conditions he entered the university at the beginning of the Lent term, 1875. During his first year he competed successfully for a scholarship at Christ's College and was admitted a scholar of that college in May 1876. He was older than the average undergraduate, and had had considerably greater experience and knowledge of chemistry, so that he was soon appointed assistant demonstrator in the university chemical laboratory. After graduating, Fenton was appointed university demonstrator, and he and his fellow demonstrator, W. J. Sell, were soon carrying out between them the greater part of the teaching in inorganic chemistry in the

university chemical laboratory; in 1904 they were given the title and status of university lecturers.

While Fenton was still an undergraduate, he encountered an observation that was to determine the main course of his subsequent research. Another undergraduate, who was amusing himself by mixing reagents at random, happened to obtain a fine violet colour. Fenton was much interested; having ascertained what reagents had been used, he determined which of them were essentially concerned in the production of the colour and reported his observation in a letter to 'The Chemical News' in 1876: 'I have lately noticed the following reaction which may, as far as I can judge at present, be proposed as a test for tartaric acid. To a very dilute solution of ferrous sulphate or ferrous chloride a small quantity of tartaric acid or a tartrate is added, followed by a few drops of chlorine water or hydric peroxide, when a fine violet colour is obtained. The violet compound appears to be potassic or sodic ferrate.'

Subsequent research showed him that his first diagnosis was incorrect, but it was not until 1894 that he was able to announce that the coloured compound was a ferric derivative of an oxidation product of tartaric acid; this product he successfully isolated as a sparingly soluble crystalline dibasic acid and showed it to be a dihydroxyethylene dicarboxylic acid of the structure $\text{HOOC.C(OH):C(OH).COOH}$. Fenton believed his compound to have the maleinoid configuration and called it dihydroxymaleic acid, though in the light of more recent research it seems almost certain that it must be dihydroxyfumaric acid.

'Fenton's reagent'—hydrogen peroxide in the presence of a trace of ferrous salt—is now known to chemists the world over. With H. Jackson and with H. O. Jones, Fenton himself examined the properties of the oxidizing agent in detail. He

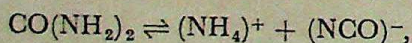
showed that while it smoothly oxidizes glycol to glycollic acid, erythritol to erythrose, and mannitol to mannose, monohydric alcohols are not attacked. It was found also that α -hydroxy acids were rapidly oxidized to the corresponding α -keto-acids, but acids of other types were unaffected. Glycollic acid gave glyoxylic acid, lactic acid gave pyruvic acid, and malic acid gave the previously unknown oxalacetic acid. Fenton's reagent is indeed a specific oxidant for compounds with vicinal hydroxyl groups, dehydrogenating a $=CH(OH)$ group to $=C:O$.

In attempting to change 'dihydroxymaleic acid' into a *trans*-modification he treated it with an ethereal solution of hydrogen bromide but found that this caused only its esterification. He was, however, thus led to try the use of hydrogen bromide and ether as an ethylating agent on other classes of compounds. He found that with certain carbohydrates—fructose in particular—it produced an intense purple colour.

With Miss M. M. Gostling he examined this reaction of fructose in detail and found that the colour arose from the further action of hydrogen bromide on a compound of the molecular formula $C_6H_5O_2Br$, which could be isolated in considerable quantity, and was subsequently identified as bromomethyl-furfuraldehyde.

Another incident encountered in teaching led him into a different field. In the Journal of the Chemical Society for 1878 he described how a pupil (Street), told to estimate urea, used instead of sodium hypobromite a strongly alkaline solution of sodium hypochlorite and obtained only half of the expected volume of nitrogen.

Fenton followed up this observation and found that the missing half of the nitrogen was left in solution as sodium cyanate. The hypochlorite had thus brought about a reversal of the Wöhler synthesis. Hypochlorites are weaker oxidizing agents than hypobromites; Fenton showed that they do not attack sodium carbamate, which is rapidly decomposed by hypobromites with the evolution of all its nitrogen. It appeared, therefore, that urea in aqueous solution is in equilibrium with a very small proportion of ammonium cyanate,



and that the hypochlorite is unable to act on the urea, but destroys the ammonia liberated from the ammonium ion by the alkali present. The equilibrium is thus disturbed, so that ultimately the whole of the urea is decomposed, with the formation of nitrogen and sodium cyanate.

Fenton was of striking appearance, with black hair, dark complexion, and athletic figure; he lectured with an air of indifference and weariness, but this was plainly a pose, for there was no missing the alertness and vitality that lay beneath.

His unsmiling, sardonic humour was curiously attractive to undergraduate audiences. Should the text-books be found guilty of over-hasty generalization—and they often were—they were denounced with scathing sarcasm. Mordant comments there were in plenty; as on Newlands and his Law of Octaves: 'But he was a chemical manufacturer; so they laughed him to scorn.'

The parts of the subject that interested him most were general and physical chemistry. He was in his early thirties when Arrhenius, Ostwald, and van't Hoff were founding the theory of dilute solutions. He had seen the birth and watched the growth of the new physical chemistry. He had lived through the controversies of that time, and he treated chemistry as a growing science. There was no dogmatism. Subjects were presented wherever possible as debatable questions on which different sides might be taken. The lecturer affected an impartial attitude, and his hearers were encouraged to balance opposing views and draw their own conclusions.

Difficult subjects were approached in the simplest way and treated with a clearness of thought that did much to lessen their difficulty. Interesting questions were suggested for further reflection; unsuspected analogies and relationships were pointed out. His lecture experiments, evolved in the course of years, were well chosen and contrived, and with the aid of his devoted lecture attendant, George Hall, he performed them with great effect.

At the close of each lecture a number of eager young men would come down to the lecture table to discuss with him some of the questions he had raised. He set great store by these informal talks and did all he could to encourage them. Students found him unexpectedly sympathetic with their difficulties, and he would deal very gently with anyone who had asked a thoughtless or ill-considered question.

Fenton retired on reaching the age of seventy and went to live at Hove. He died in a London nursing home on 13th January 1929. The whole of his working life had been spent in the Cambridge University Chemical Laboratory, where his almost fabulous success as a teacher is still vividly remembered.

Histological procedures in cancer research

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E. S. HORNING

In Great Britain cancer is the second most common cause of death, and approximately one person in ten is destined to suffer from it; in other parts of the world the situation is comparable. Why the normal multiplication of cells, which even in the adult continues to make up for wear and tear, may suddenly become unrestrained is still unknown, but research has nevertheless led to results of clinical importance in both diagnosis and treatment. Histological research has proved particularly valuable, and some of its results are discussed here.

Cancers consist of masses or growths of newly formed cells which arise in the first place from normal body cells but which, for reasons as yet unknown, continue to divide and multiply without restraint. The new cells cease merely to replace the old ones and begin almost immediately to grow independently of the rest of the body. Their multiplication becomes unlimited, progressive, and uncontrolled; consequently in many cases they invade the surrounding healthy tissues and organs and, if not checked, may rapidly spread throughout the body. The spreading is often accelerated by the breaking away of small groups of cancer cells from the primary growth; these are carried by way of the blood and lymph to quite distant parts of the body. Here they lodge, forming secondary foci or metastases. If vital organs and tissues become obstructed, deranged, or destroyed, death of the whole organism is inevitable.

Unlike many other familiar diseases, cancer is by its very mode of origin almost unlimited in the variety of its manifestation. Some growths or tumours, for instance, remain strictly localized at their point of origin. Some indeed grow so slowly, without spreading, that the tumour may be little more than an inconvenience or an unsightly blemish. Such tumours are classified as benign, in contrast to the malignant variety mentioned above. The clinician must determine not only whether tumour cells exist in the body, but whether they are growing as a benign or as a malignant tumour, and what variety of normal cell originally became cancerous. Thus it is usually a matter for grave concern if the pigmented cells of the body or the blood cells are involved, whereas if it is simply a question of fat cells proliferating the outlook may be much more hopeful.

MICROSCOPY IN DIAGNOSIS AND RESEARCH

Much of the knowledge we have obtained of differences in behaviour between normal and

malignant cells, and in particular of the mode of growth and infiltration of cancer throughout the body, has been obtained by the use of the microscope. The actions of radiations, drugs, chemicals, or hormones upon a malignant growth, and the ultimate fate of the cancer cell after any of these forms of treatment, can be revealed by the histological or cytological approach. A thin slice or section of the cancerous tissue is generally needed; this can be stained to emphasize structural characteristics. In some cases, where minute groups of cancer cells can be isolated, it is sufficient to smear them on a glass slide before staining. There is a vast literature dealing with the purely descriptive aspects of the histological and cytological structure associated with different forms of cancer, including the early stages when the neoplastic changes are first detectable. While the techniques of sectioning and microscopy, when routine diagnosis of cancerous conditions is required, are much the same as those used in conventional histology, some techniques have been specially adapted for work in this field.

TRANSPLANTATION OF CANCER IN ANIMALS

In order to study the structure and behaviour of the cancer cell it is necessary for the cellular pathologist to have available living malignant cells. Most cancer research laboratories keep inbred strains of mice in which a high percentage develop spontaneous tumours, as well as rodents of indeterminate ancestry which can bear grafted or transplantable cancers. The cytologist depends mainly on the latter material.

At the close of the last century it was discovered that certain spontaneous animal tumours could be transferred by grafting small pieces of the tumour under the skin of animals of the same species. In this way cancer can be propagated from animal to animal for an unlimited number of generations. Some animal neoplasms, such as the Walker carcinoma, have been kept going continuously for



FIGURE 1 - Photomicrograph, by direct illumination, of a control section of a mouse tar-tumour, showing tarred skin, stroma, and underlying tumour cells. The preparation was stained with Ehrlich's haematoxylin, after fixation in alcohol-formalin. ($\times 150$)

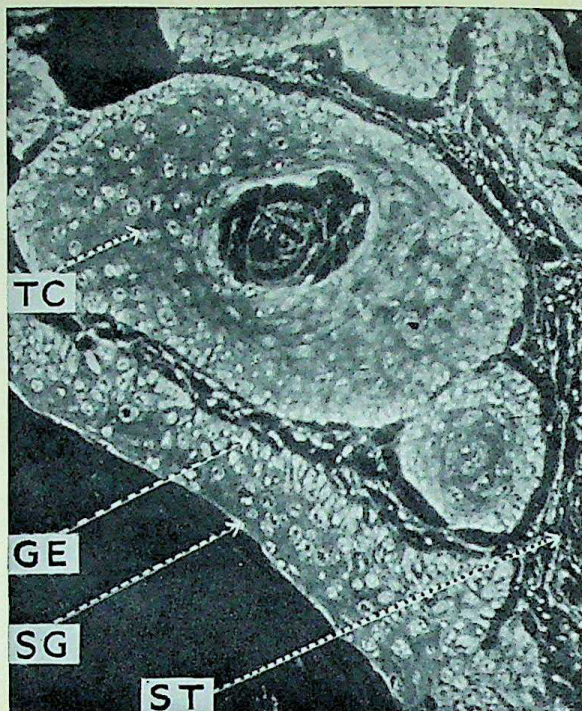


FIGURE 2 - Incineration section, similar to that seen in figure 1, photographed in dark field illumination. SG = tarred skin; TC = underlying tumour cells. ($\times 150$)

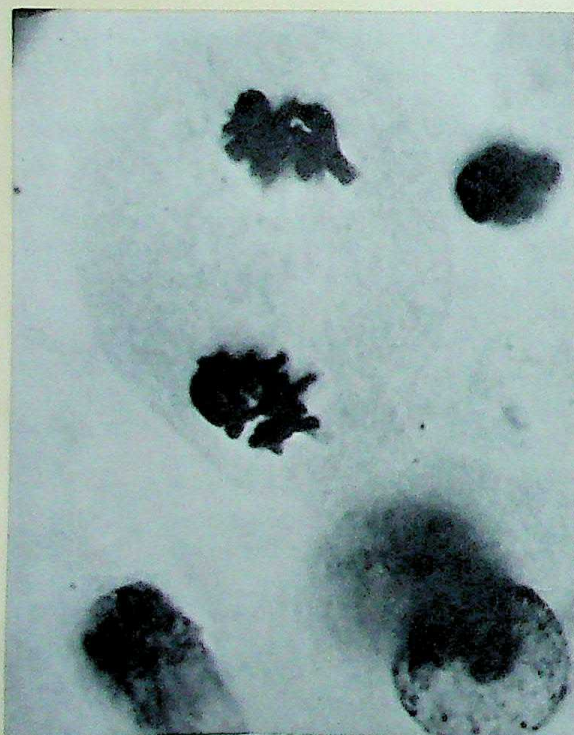


FIGURE 3 - Normal division (anaphase) in a transplanted Walker rat tumour. ($\times 2500$)



FIGURE 4 - Illustration of the effects of HN2, 24 hours after injection, on the chromosomes of a Walker tumour. ($\times 2500$)

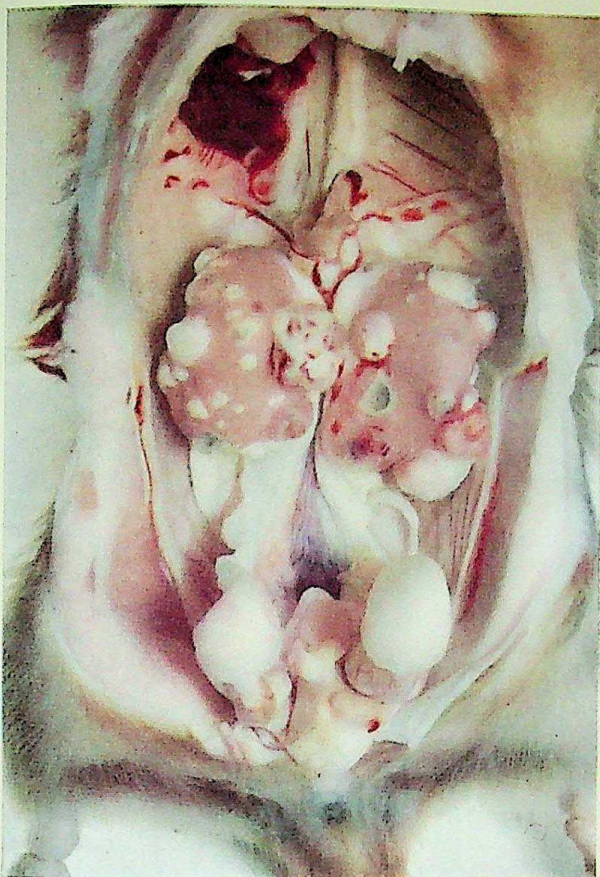


FIGURE 5 - Multifocal malignant nodules in both kidneys of a male hamster following prolonged treatment with stilboestrol. (Natural size.)

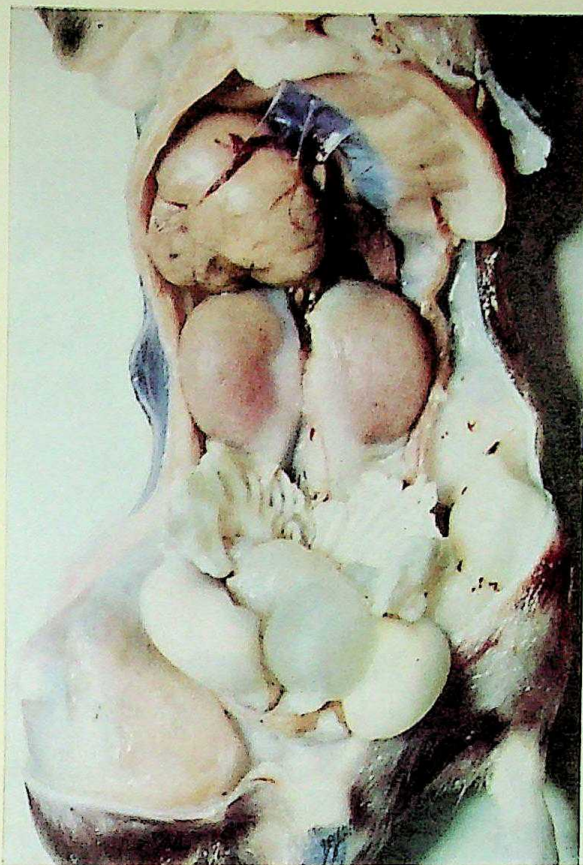


FIGURE 6 - Kidneys of male hamster without tumours; compare with figure 5. (Natural size.)



FIGURE 7 - Isolated group of human carcinoma cells seen in urine deposit of man suffering from advanced cancer of the bladder. ($\times 1000$)



FIGURE 8 - The same material as for figure 7. One malignant cell is seen in division. Note abnormal chromosome. ($\times 1000$)

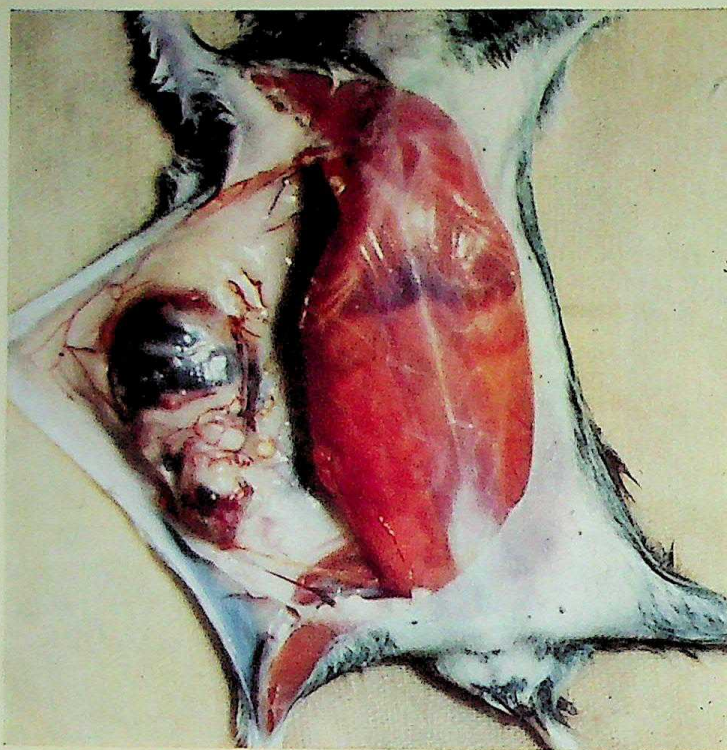


FIGURE 9 - *Transplantable renal tumour growing subcutaneously in a male hamster which had previously been treated with stilboestrol. ($\times \frac{1}{2}$)*

nearly half a century. Tumours in animals which have been induced by a chemical carcinogen are also transplantable in some cases. Figure 9 shows a transplantable renal tumour growing under the skin of a host male hamster. This particular kidney tumour was induced in a male hamster following treatment with diethyl-stilboestrol, a synthetic oestrogen having an action similar to that of the female sex hormone. These tumours arise only in oestrogen-treated males and never in females (see figures 5 and 6); renal tumours can rarely be grafted and will in fact respond to grafting only if the new host hamster has first been treated with oestrogen. With material of this kind, and with the great variety of spontaneously occurring human and animal cancers, the histologist and cytologist can work.

ABNORMALITIES OF THE CANCER CELL

The two most common cytoplasmic constituents of both normal and malignant cells are the mitochondria and the Golgi bodies. In some cancer cells these inclusions undergo morphological changes which seem to be dependent upon the degree of cellular differentiation and the func-

tional state of the cell. Numerous investigations have shown, however, that similar changes can be produced experimentally in normal healthy cells, and that there are really no microscopical features of the cytoplasm that can be relied upon to distinguish a cancer cell from a normal one. Greater attention has been focused, therefore, on the nucleus. It has been known since last century that the successive stages of the scanty cell divisions seen in benign tumours usually appear normal, but that in rapidly growing malignant cancers the mitotic figures which appear in cells during division are more frequent, and many types of nuclear abnormalities appear. The proportion of cancer cells that are dividing at any given time is, of course, an indication of the rate of growth of a tumour. According to Willis [1], rapidly growing tumours may show mitotic figures in 5 per cent or more of their cells, and the proportion never exceeds 10 per cent. Stroebe [2], Pianese [3], von Hansemann [4], and others described structural abnormalities such as hyperchromatism (increased staining of the nuclear contents), giant multiple nuclei, enlarged nucleoli, and abnormal cell divisions. Great hopes were raised that these nuclear

abnormalities might be an essential feature of malignancy, until it was found that abnormal mitosis can be induced in normal cells by chemical agents. They can also be seen in ordinary tissues regenerating after injury (Cowdry [5]). This problem has been reviewed by Levine [6], Ludford [7], and Koller [8].

Many cancer cells possess a tetraploid or polyploid number of abnormal chromosomes. Koller, studying material obtained from transplantable rodent tumours as well as human cancers, has discussed the factors causing failure of cell division, and other mechanisms which induce chromosome abnormalities. Most frequent is 'stickiness' of the chromosomes, which are irregular or polyploid in number and the division of which is invariably accompanied by a partial or complete suppression of the mitotic spindle. According to Koller, these abnormalities are due to lack of adequate food supply, as well as to the accumulation of toxic breakdown products.

Although many therapeutic agencies can induce nuclear abnormalities in the normal cell, the cancer cell is so often abnormal in nuclear structure that much more reliance can be placed upon structural changes in the nucleus than upon almost any other supposed criterion of malignancy.

DIAGNOSIS BY THE SMEAR TECHNIQUE

The routine histological procedure for cutting sections is not only rather slow for the purpose of cancer diagnosis, but is apt to distort the cells in such a way that nuclear abnormalities are less easily detected. The smear technique was used by Belling [9] for the comparative study of animal and plant chromosomes, and it became very well known when Papanicolaou showed that smears of cells swabbed from the lining of the vagina of various mammals could be used in assessing the stages of the sexual cycle. Koller [10, 11] was one of the first to employ the smear technique in the study of experimental cancer in animals (see figure 7). Small fragments of cancer tissue or drops of body fluids containing cancer cells, for example from the peritoneal cavity, are placed on a slide. After the tissue has been carefully teased to separate the cells, a few drops of a combined fixing and staining solution are added. It takes only 5-10 minutes to complete the preparation. The advantage of such a simple technique in cancer diagnosis is obvious, provided, of course, that the small fragments of tissue can be taken at biopsy or isolated from such fluids as urine.

Equally important is the use of the smear tech-

nique in certain kinds of chemotherapeutic research. It helps the cytologist in observing a sequence of changes if repeated samples are taken during the course of a prolonged experiment, and gives valuable information in determining the correct dosage of a particular therapeutic agent. Within limits, the degree of malignancy can be assessed at frequent intervals, and this is often quite important in tumour material showing variations in growth behaviour. Koller [11] has also applied the technique to a comparative study of the responses of normal and malignant cells to various carcinogenic agents. These studies show that abnormal chromosome behaviour is one of the most important signs by which cell reaction to chemical agents can be measured (figures 3 and 4).

Although the smear technique appears very simple, it requires considerable experience to obtain preparations free from cellular distortion; no amount of skill will enable even an experienced cytologist to diagnose cancer cells unless the material has been carefully collected. Special training in nuclear cytology is required to arrive at a reliable diagnosis. The smear technique cannot be used for a rapid diagnosis of every type of cancer, and in human cases confirmation of the initial findings is usually obtained from biopsy material examined in sections, or, in the case of prostatic cancer, by certain chemical tests.

Cancers of the urinary bladder, the lung, the breast, and, to a lesser extent, the female genital tract provide the material most successful for cyto-diagnosis. Figure 7 shows a smear of cells isolated from the urine of a man suffering from advanced cancer of the bladder. Isolated groups of cancer cells, readily recognizable by their cytological character, include a cancer cell in division at the time of fixation and showing an abnormal chromosome (figure 8). Routine biopsies of the bladder are difficult to obtain, and this example forcibly illustrates the great advantage of this method.

Albers, McDonald, and Thompson [12] have applied the smear technique in the United States for detecting cancer of the prostate gland, which also is rather inaccessible for routine biopsy. In several instances they have detected malignant changes in the prostate by the smear technique even before the disease was clinically evident. This is quite important, because in some individuals the prostate gland undergoes benign hypertrophy rather than a truly cancerous change. During the past twenty years or so much work has been done on smears of human sputum from patients suffering from bronchial carcinoma. Owing to the

alleged correlation between cigarette smoking and lung cancer we may expect new modifications of staining technique as applied to smear preparations. Recently an interesting annotation [13] was published on the diagnosis of bronchial cancer; in this the value of the smear technique was particularly stressed, as this form of cancer may not become apparent in X-ray films until far advanced. It is stressed that considerable experience is needed to distinguish cancer cells from others found in the bronchial exudate. The results of Jennings and Shaw [14] are quoted as confirming the value of smear examination, since 82 per cent of patients with bronchial tumours gave a positive smear diagnosis, whereas only 45 per cent could be identified as having the disease when other methods of diagnosis were used. In almost two-thirds of cases in which cancer was located at the periphery of the lungs, beyond the range of bronchoscopic vision, a positive sputum test was recorded.

Similarly in breast cancer the smear technique has great advantages, but there is a complex cellular exudate from the mammary gland, even in the absence of cancer, which makes it unwise to base a diagnosis of malignancy on a single preparation. Osborn has discussed some pitfalls of cytodagnosis and, for those who wish to learn more, his book [15] is strongly recommended, as well as another interesting monograph [16].

MICRO-INCINERATION OF CELLS

This technique, in which thin sections of suitably fixed tissues are incinerated at high temperatures, leaving behind the inorganic components of the cells, is not a histological technique that can help in the diagnosis of cancer, but it can be applied to a limited range of research problems. After the sections have been incinerated on quartz or glass

slides, they are first examined by transmitted light to ensure that carbon residues have been removed. In dark field illumination the ash can be seen as a more or less opaque white deposit preserving with remarkable clarity the contours and internal structure of the individual cells. Only three substances—compounds of calcium, iron, and silicon—can be identified with any certainty by their colour in dark field illumination or, in the case of silica, by its birefringence in polarized light. Until more precise methods are devised for the identification of the ash components, the value of the method lies principally in the determination of variations in total non-volatile ash content and in its distribution. Variations are considerable in tumours and appear to be correlated with varying degrees of cellular differentiation. Scott and Horning [17] have recorded mineral content changes in neoplasms associated with different degrees of malignancy (figures 1 and 2).

The effect of radium treatment upon the mineral organization of transplantable cancer cells in rodents has been studied by Horning [18], who found that a marked increase of calcium occurred in tumour cells as early as 6–8 hours after irradiation, reaching a maximum on the sixth day. The initial increases seemed to indicate that the permeability of the cell membranes to calcium ions had been increased by the radium radiations. This technique has been used to examine the mineral organization in many other pathological conditions (Horning [19, 20]).

ACKNOWLEDGMENTS

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The origin of lizards

E. KUHN-SCHNYDER

The problem of the evolution of lizards is of considerable biological interest, since they represent an important vertebrate sub-order. While much information has been obtained from fossil remains, there has been a dearth of direct palaeontological evidence for the period separating the lizard-like *Prolacerta* of the Lower Triassic from the true lizards of the Upper Jurassic. New light has been thrown on this critical period by excavations at Monte San Giorgio (Switzerland), with which the writer of this article has long been associated.

Up to some 300 million years ago, the only vertebrates were fishes, populating lakes, rivers, and seas. One group then succeeded in making a decisively important step: the emergence from water on to land. To meet the new needs a form of spinal column was evolved that was at once mobile and capable of bearing weight. The need was fulfilled in the most varied ways among amphibians, and one of the designs was used for the reptiles, which, however, became fully emancipated from aquatic life. There were various changes in the construction of the skull. To allow freedom of movement of the head, a typical neck was developed. One group of reptiles acquired the capacity to chew food, a normal prerequisite for warm-bloodedness, and this developed into the mammals, among which the development of dentition was of exceptional importance (figure 1).

Those parts of the skeleton that were undergoing profound modification during a given period of evolutionary change are particularly suited for characterizing the various forms typical of that stage of organization. Thus, the spinal column is significant for amphibian systematics; the structure of the skull for reptiles; the study of dentition in mammalian systematics. In discussing the origin of lizards (Squamata, sub-order Lacertilia),

decisive results are therefore to be expected from consideration of the structure of the skull.

The oldest reptiles (Cotylosauria) show, like their amphibian ancestors (Labyrinthodontia), a closed cranial vault. They are therefore known as Anapsida, reptiles without arches or vaults. The tortoises and turtles show a survival of this condition, with some modifications. Descendants of the early anapsid reptiles had a stronger jaw-musculature, and for the attachment of these muscles there developed cavities in the temporal areas of the skull. These cavities were limited by temporal vaults (figure 2). H. F. Osborn [16] separated the reptiles into two sub-classes, Synapsida and Diapsida, according to whether they had one or two temporal arches respectively. Broadly speaking, Osborn's concept was correct: as knowledge of types of fossil reptiles grew, two successful lines of development became increasingly obvious. The Archosaurs, whose origin can now be traced back to the Triassic, were the dominating vertebrates of the Jurassic and the Cretaceous (Dinosaurs); they culminated in the birds of today. All the representatives of these classes, to which the crocodiles also belong, are either diapsids or descended from diapsids. The other, synapsid, line led from the Pelycosaurs of the Permian,

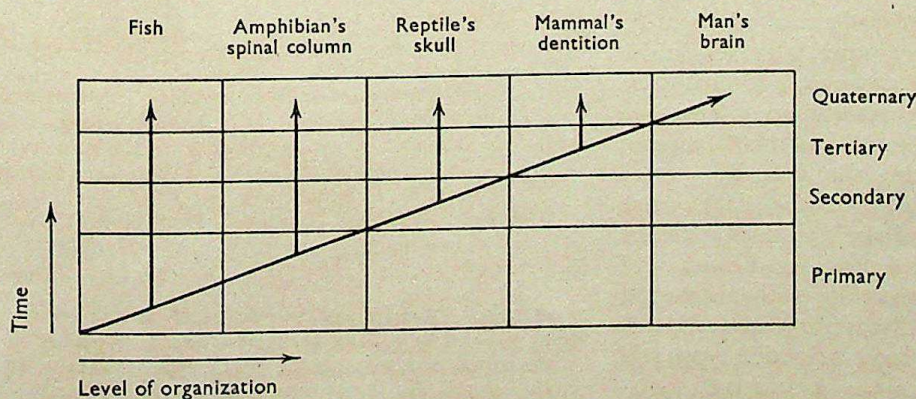


FIGURE 1 — Stages in organization of vertebrates.

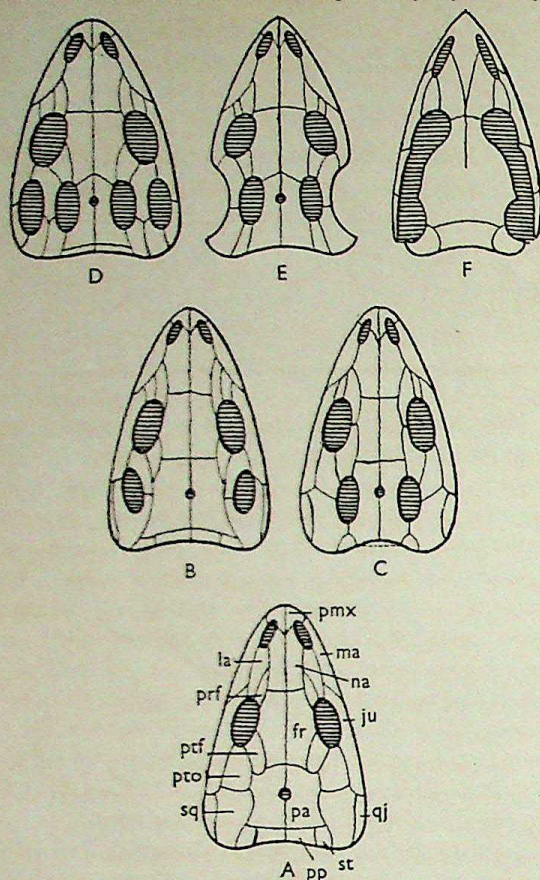


FIGURE 2 - Diagrammatic representation of cranial relationships in reptiles and birds. A, anapsid; B, synapsid; C, parapsid; D, diapsid; E, Squamata (lizards); F, Birds. Key: fr = frontal bone; ju = jugal; la = lacrimal; ma = maxillary; na = nasal; pa = parietal; pmx = premaxillary; pp = postparietal; prf = prefrontal; ptf = postfrontal; pto = postorbital; qj = quadratojugal; sq = squamosal; st = supratemporal. (Based on drawings by R. Broom.)

through the Therapsida of the Permian and Triassic, to the mammals. In the shadow of these progressive groups of reptiles, however, other branches survived: ancestors of tortoises, of lizards, and of the Rhynchocephalia (*Sphenodon* and others). To these must be added other types, which chose the sea to live in but which became extinct during the Mesozoic (figure 4). The splitting up of these side branches began towards the end of the Palaeozoic and was completed during the Triassic.

Palaeontology alone can show the exact course of the history of the animal world; if fossil evidence is lacking, one can only speculate on the course of evolution. Until quite recently, palaeontologists had not succeeded in discovering fossil lizards more primitive than the most primitive types still living; decisions on the place of lizards in syste-

matics depended therefore on interpretation of the results of comparative anatomy and embryology. M. Fürbringer [11], who had made a detailed anatomical study of the construction of the chest and shoulder region in living reptiles, came to the conclusion that lizards and Rhynchocephalia were closely related; he put them in the subclass Toco-sauria, in which he also included the marine ichthyosaurs. In 1937, Sir Gavin de Beer [2] came to the same conclusion on the basis of embryological investigations. Among palaeontologists opinion was divided. Some distinguished workers (S. W. Williston [25, 26], D. M. S. Watson) supported a sharp systematic separation between lizards and Rhynchocephalia.

There are, in fact, considerable differences between lizards and Rhynchocephalia (figure 3). The skull of the latter shows two temporal openings, and hence an upper and a lower temporal arch. The typical lizard cranium, on the other hand, has only one temporal opening. Moreover, the behaviour of the quadrate, the bone of the skull which provides the articulation with the lower jaw, is distinctive. In most lizards the quadrate is mobile, a condition known as streptostyly. The quadrate in the Rhynchocephalia is joined solidly to the skull, a condition known as moni-mostyly. The relationships of the lizard skull can be interpreted in two ways. According to one, they originally possessed two temporal openings, like the Rhynchocephalia; if the lower temporal arch was then reduced, we should have the relationship existing today. According to the other,

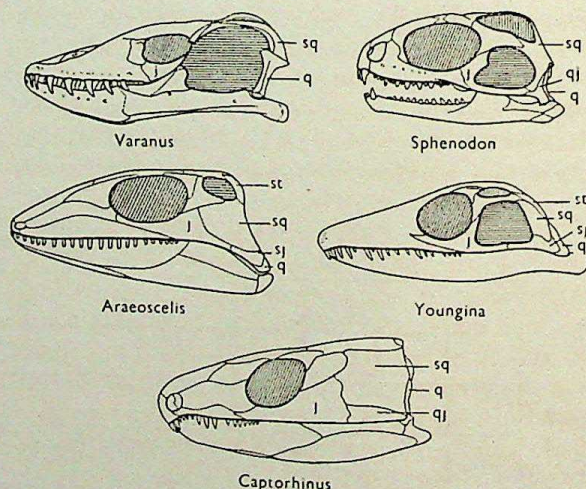


FIGURE 3 - Primitive and developed skull types in reptiles. Key: j = jugal; q = quadrate; qj, sj = quadratojugal; sq = squamosal; st = supratemporal. (Based on drawings by R. Broom, W. K. Greenwood, and A. S. Romer.)

the lizard cranium originally possessed only one temporal opening; if this is proved true, there can be no question of a close relationship between lizards and Rhynchocephalia.

A fossil skull found in Texas in 1912, and another found in South Africa a year later, were each claimed as a demonstration of the correctness of one or other of the two hypotheses. S. W. Williston [25, 26] believed he had discovered the ancestral type of the lizard in *Araucoscelis*, from the Permian-Carboniferous in Texas. *Araucoscelis* has only one temporal opening and an immobile quadrate, and Williston was convinced that the link with the lizard skull had been made by emargination of the temporal bone and subsequent streptostyly.

Not all palaeontologists, however, were convinced by *Araucoscelis*. R. Broom, in particular, did not agree, and in the same year he described [4] the skull of a fossil reptile, *Youngina*, from the *Cistecephalus*-zone of the Beaufort Beds (Upper Permian) in South Africa, which showed two temporal openings. If the lower temporal arch is reduced, the quadrate becomes capable of movement. *Youngina* also shows a bone, the supra-temporal (tabulare Broom), on the posterior, inner edge of the upper temporal opening, which persists in the lizards living today. No supra-temporal is present in the Rhynchocephalia, but their ancestors show it. Only a few further finds of *Youngina* and related types have been made in South Africa [9], that treasure-house of fossil reptiles, and Broom [5, 6] classed them together under the name of Eosuchia (figure 5). No trace of a true lizard was found, and resignedly it was supposed that they had developed only much later, in Upper Jurassic or Cretaceous times.

It was, however, again South Africa that, in 1935, drew the attention of palaeontologists. In that year F. R. Parrington [17] described a small lizard-like reptile—*Prolacerta*—from the Lystrosaurus Beds (Lower Triassic). In the same year, C. L. Camp [10] discovered a further specimen, which he investigated and described in detail. *Prolacerta* occupies a place midway between *Youngina* and the lizards (figure 5). The lower temporal arch of *Prolacerta* is not closed and the quadrate is streptostylic. The derivation of lizards from types having two temporal openings was thus made certain: lizards and Rhynchocephalia are therefore closely related.

At this point mention must be made of a further peculiarity of the reptilian skull. According to J. Versluys, the lizard cranium is kinetic [22]. It consists of two sections, having no solid connec-

tion with one another: an occipital segment can be moved against a maxillary segment. When the mouth is opened, the occipital segment remains fixed to the vertebral column; special muscles move the maxillary against the occipital segment. The cranium of the Rhynchocephalia lacks this mobility. Which behaviour is the more primitive?

Palaeontology can show that a kinetic skull is found in the ancestral forms of the reptiles; *Youngina* and *Prolacerta* both have such skulls. In this respect the lizard skull has remained more primitive than that of the Rhynchocephalia. The akinetic skull of Rhynchocephalia represents a modification: it is specialized for a particular manner of feeding and the dentition is highly specialized. Besides worms and insects, the tuatara (*Sphenodon*) eats snails and mussels. That the skull of the Rhynchocephalia must be descended from a type having a kinetic skull accords with embryological research. The articulated connection between the two cranial segments, the basi-pterygoid joint, is well developed in the embryo; the associated muscles are attached, but later regress.

The connections between Lepidosauria (lizards, Rhynchocephalia, and related reptiles) and Archosaurs need a little more explanation. Both groups have a primitive skull with two temporal openings,

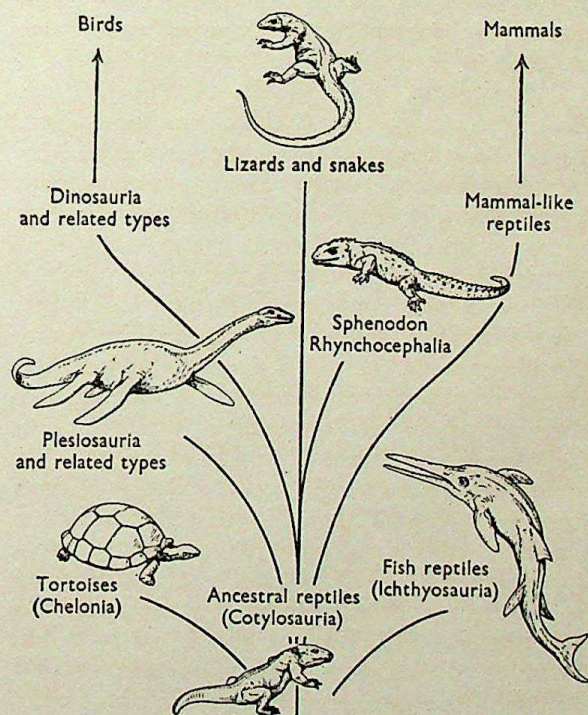


FIGURE 4—Main and side branches of reptiles. (Based on drawing by A. S. Romer.)

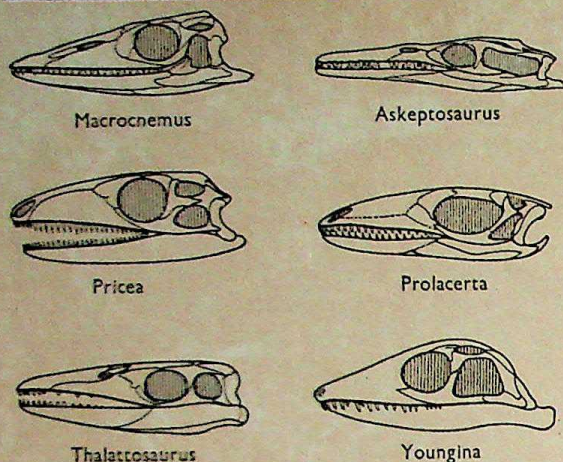


FIGURE 5 - *Eosuchia* and early *Squamata*. According to R. Broom; R. Broom and J. T. Robinson; C. L. Camp; E. Kuhn-Schneider; and A. S. Romer.

but their present-day representatives show fundamental anatomical differences. Thus crocodiles (Archosaurs) have a simple penis and an elongated cloacal opening, while lizards and snakes have a transverse cloacal opening and a double penis. Experience teaches us caution in using the nature of the temporal opening as a systematic criterion, for it depends originally on the formation of the jaw musculature and on the dentition; that is to say, on the kind of feeding. In certain circumstances a parallel development might have occurred in both Archosaurs and Lepidosaurs.

Prolacerta dates from the Lower Triassic; true lizards do not appear until the Upper Jurassic [3]. To discover if our proposed type sequence were correct it needed confirmation by further finds from within this enormous time-span of about 50 million years. Excavations in the southern Alps, initiated in 1924 by B. Peyer, the present director of the zoological museum of Zürich University, have shed new light on this subject. The author was fortunate in that, as a young student, he was able to take part as early as 1925 in these excavations, which were made possible by donations from the 'Georges und Antoine Claraz-Schenkung.'

At Monte San Giorgio, south of Lugano, there are deposits from Tethys, the great Mediterranean sea of former ages. Bituminous layers, which alternate with beds of dolomite, are especially rich in reptiles and fishes belonging to the upper section of the anisian stage of the Triassic (Middle Triassic). Bodies of marine reptiles (Ichthyosaurs) were washed up on this shore, and Saurians which led an aquatic life are dominant in these beds. There are numerous examples of the Sauropterygia,

which used their limbs for swimming. Associated with them are the Placodontia, whose jaws are provided with large, blunt teeth which they used for crushing their hard-shelled prey. The Monte San Giorgio deposits are at present the richest source of marine reptiles of the Middle Triassic. Marine vertebrate fauna of equal antiquity are known only from Spitsbergen and Nevada. Moreover, the shore-deposits of Monte San Giorgio also shelter the remains of reptiles that led an amphibious life or did not normally inhabit the sea. Among them is a type-series of reptiles, the position of which in the natural system has up till now been very uncertain: *Tanystropheus*, *Macrocnemus*, and *Askeptosaurus*.

It is a striking fact that the majority of our finds consist of more or less complete skeletons: the embedding of the bodies must have occurred quickly. The skeletons, especially in the bituminous layers, are invariably compressed and deformed without breakage; the extent of this strong deformation indicates that the watery ooze settled down to just over a tenth of its original bulk. Reconstruction of the parts is usually necessary to give a proper idea of the structure of the deformed skulls and shoulder and pelvic girdles. X-ray photographs (figures 6 and 7) have proved a valuable aid to the preparation of specimens and their scientific interpretation.

We were not the first to excavate systematically the Triassic beds of the southern Alps. In 1863 and 1878 the Milanese worked in bituminous shales near Besano (Varese, Italy). F. Bassani [1] gave a brief report on these researches in 1886, but the great monograph which was heralded was never published. Only a few experts knew what interesting vertebrate remains were hidden in the Milan Museum, and only one foreign palaeontologist, the Hungarian Baron Franz von Nopcsa, visited Milan frequently. He studied the puzzling 'flying reptile,' *Tribesodon* [13], and made a reconstruction of it, and he also took an interest in the remarkable *Macrocnemus* [15]. He discovered, too, a reptile overlooked by Italian palaeontologists, *Askeptosaurus italicus* [14]. We succeeded in excavating complete remains of these three.

Nopcsa was a research worker with original ideas, but it remains to be seen which of the ideas he put forward are sound. In the light of recent research, his conclusions on the systematic position of *Askeptosaurus*, *Macrocnemus*, and *Tanystropheus* may be assessed as follows.

Askeptosaurus italicus Nopcsa. In 1925 Nopcsa [14] had only a small hip-bone (ilium) and the

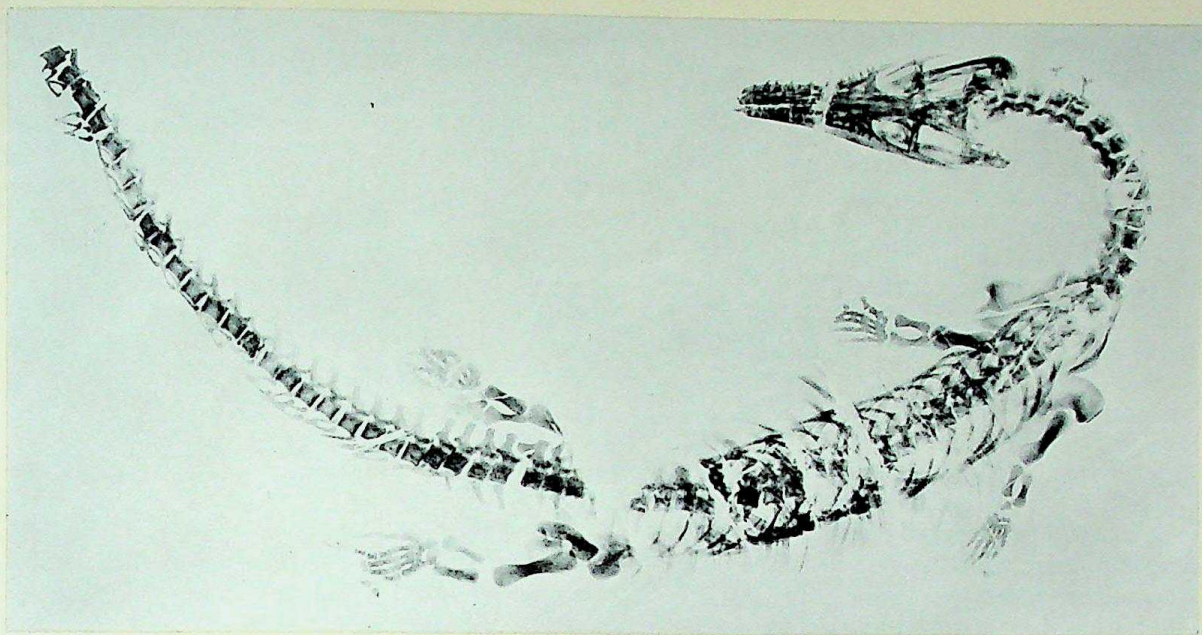


FIGURE 6 – *Askeptosaurus italicus* *Nopcsa*; from an X-ray photograph prepared at the X-ray Institute of the Cantonal Hospital, Zürich (Director, Professor H. R. Schinz). (After E. Kuhn[-Schnyder], 1952.) ($\times \frac{1}{7}$)



FIGURE 7 – *Tanystropheus longobardicus* (Bass.). From an X-ray photograph prepared at the X-ray Institute of the Cantonal Hospital, Zürich (Director, Professor H. R. Schinz). (From B. Peyer, 1931.) ($\times \frac{3}{7}$)

microscopical structure of the ribs on which to base his identification of this new genus and species (figure 8). He came to the conclusion that these were the remains of a type of reptile previously unknown, probably belonging to the type-series of older lizards, about which so little was known up to that time. Investigation of the new material by E. Kuhn[-Schnyder] [12] showed that *Askeptosaurus* has two temporal openings, the lower of which is not closed (figures 5, 6). A supratemporal is present. The quadrate is mobile, the skull kinetic. Despite the scarcity of material Nopcsa recognised the systematic position of this fossil with unusual perspicacity; *Askeptosaurus* is a specialized representative of early lizards. Besides some characteristics typical of life on land, its skeleton shows a number of peculiarities which can be explained only by assuming an amphibious mode of life.

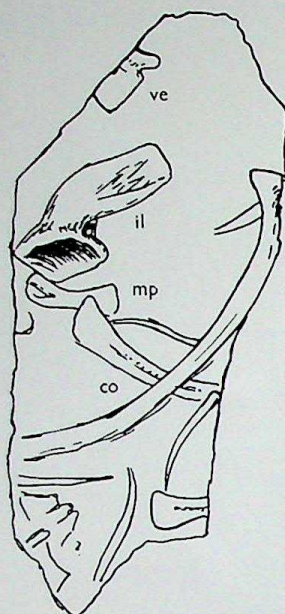
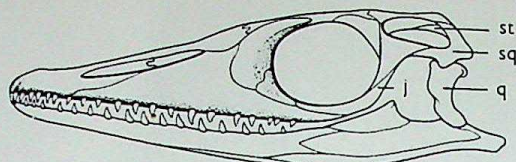
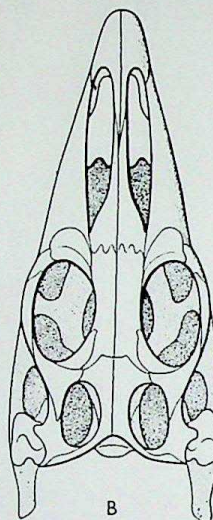


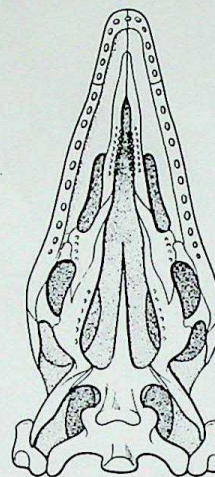
FIGURE 8 - Type specimen of *Askeptosaurus italicus* Nopcsa. Key: il = ilium. (After F. v. Nopcsa, 1925.) (Approx. natural size.)



A



B



C

FIGURE 9 - Reconstruction of skull of *Macrocnemus bassanii* Nopcsa. A, Side view; B, seen from above; C, seen from below. Key: j = jugal; q = quadrate; sq = squamosal; st = supratemporal. (E. Kuhn[-Schnyder].)

It is related to the marine *Thalattosaurus* from the Upper Triassic of California.

Macrocnemus bassanii Nopcsa. The badly preserved remains of one originally complete specimen were all the material available to Nopcsa [15] in 1930. In his short note he has, therefore, given only a diagram (figure 10) to show the remarkable proportions of the animal. Nopcsa placed *Macrocnemus* close to the Permian genus *Araucoscelis*; in 1937 the new material was described by B. Peyer [19] in a comprehensive monograph. Detailed comparison with *Tanystropheus* shows certain relationships. Here, too, Nopcsa's opinion seemed to be further confirmed. Peyer [20] first placed *Macrocnemus* with *Tanystropheus*, and *Protorosaurus* and *Araucoscelis* among the Protorosaurs, and he further emphasized a relationship with the Squamata and the Rhynchocephalia. As it was not possible to explain the cranial structure of *Macrocnemus* with sufficient clarity, the writer has recently attempted a plastic reconstruction with the aid of further fresh material now available. There is no doubt about the results (figure 9). *Macrocnemus* has two temporal openings; the lower temporal arch is incomplete; the quadrate is

streptostylic, the skull kinetic; a supratemporal is present. *Macrocnemus* must be placed in the type-series of the older lizards. There is no close relationship to *Araucoscelis*. The skull structure of *Protorosaurus* remains as yet unknown.

Tanystropheus longobardicus (Bassani). A find from Besano was at first described by F. Bassani [1] in 1886 as *Tribelesodon longobardicus*, and Nopcsa [13] made a fresh investigation in 1923; both authors referred to it as the earliest flying reptile (figure 11). A few vertebrae and the remains of a lower jaw came to light as a result of a fall of rock in one of the galleries of the Cava Tre Fontane on Monte San Giorgio in the spring of 1927, and it was possible to identify the vertebrae as belonging to the mysterious *Tanystropheus*. Such vertebrae, which had been known for more than a century from the *Muschelkalk* of Bayreuth, had been identified as tail-vertebrae of dinosaurs. In the summer of 1929 the Museum's excavations yielded the fossil shown in figure 7; the vertebrae of *Tanystropheus* are in fact neck-vertebrae. The enormous length of the neck of this reptile is attained, like that of the giraffe, by elongation of the separate vertebrae. Further examination of the Milan fragment of

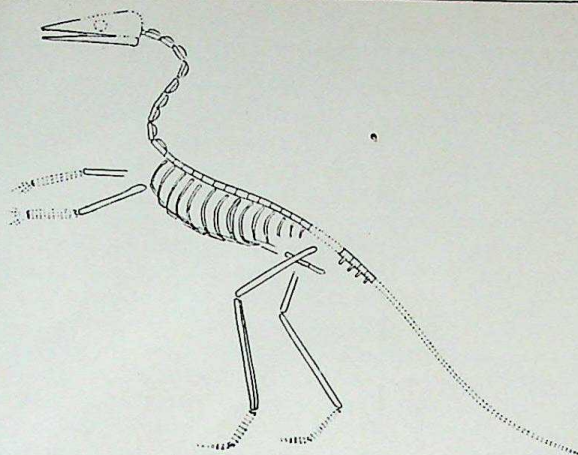


FIGURE 10 – *Macrocnemus bassanii* Nopcsa. The dinosaur-like attitude of the animal is not correct. (After F. v. Nopcsa, 1930.) ($\times \frac{1}{2}$)

Tribelesodon has shown that the supposed flying reptile is in fact *Tanystropheus*. The series of elongated neck-vertebrae was interpreted by Bassani and Nopcsa as being elements of the wing finger. A monograph on the new finds of *Tanystropheus* was published in 1931 by B. Peyer [18], who was originally inclined to identify *Tanystropheus* as one of the Sauropterygia, types which have one temporal opening. The systematic position was further clarified by the evidence of its relationship with *Macrocnemus* [19]. A reconstruction of the lower side of the cranium, which the writer made a few years ago, did show that in fact the skull of *Tanystropheus* is kinetic. The quadrate is streptostylic, and the lower of the two temporal openings is not closed. *Tanystropheus* was a highly specialized lizard living, in the Middle

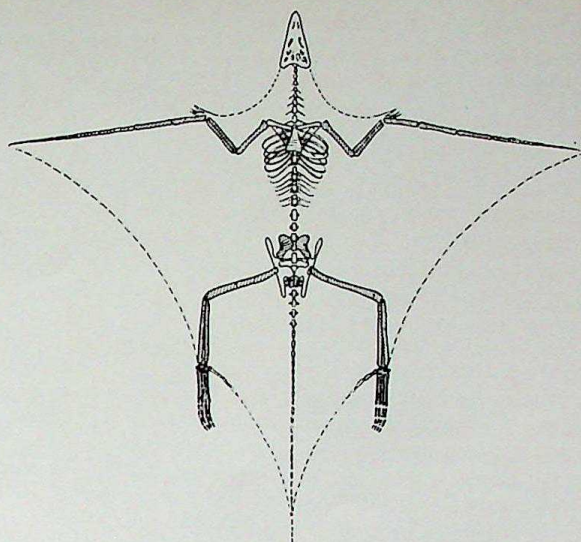


FIGURE 11 – Incorrect reconstruction of *Tribelesodon* (*Tanystropheus*) as a parachute-flyer. (From F. v. Nopcsa, 1923.) ($\times \frac{1}{2}$)

Triassic, on the coasts of both Tethys and the Germanic inland sea. It could attain a total length of about 6 metres, though the functional significance of the elongated neck remains a riddle.

Askeptosaurus, *Macrocnemus*, and *Tanystropheus* show that the lizards date back to the Middle Triassic, and the occurrence of these specialized types is evidence for the view that the lizards were passing through a first period of development at even that early date. The drift to the sea was already going on; *Askeptosaurus* and *Thalattosaurus* confirm this. During the Cretaceous, a branch of the lizards, the mighty Mosasaurs, went back again to the sea.

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Book reviews

HONOUR TO CHARLES SINGER
Science, Medicine and History. Essays in honour of Charles Singer. *Two volumes, edited by E. Ashworth Underwood. Pp. 563 and 646. Oxford University Press. London. 1953. 11 gns. the set of two volumes.*

It is a matter for genuine satisfaction that the steadfast and richly fruitful devotion of a long career to science and scholarship should be thus recognized and honoured. It is truly a magnificent tribute to the life's work and inspiring influence of Charles Singer as investigator, teacher, and powerful advocate of the study of medical and scientific history, that Dr Ashworth Underwood has assembled, edited, and brought to publication. It presents a most impressive array of contributions of great distinction, from scientists and scholars of many countries who belong to the wide circle of Dr Singer's friends and admirers. Its organization and production must have involved a labour of affection over an extended period, for several of the eminent contributors have already been dead for some years. No fewer than ninety in all have filled these two handsome volumes with essays and articles of the most widely varied character and interest, but having the common aim of casting new light, from their different angles, on the history of medicine, and that of a much more extensive range of experimental science and philosophical speculation. Their object was to honour the man whose outstanding services to scholarship, in this wide field of their common interests, they all desire to acknowledge, and to applaud; it would be difficult, impossible indeed, to imagine a handsomer tribute to any man's life-work and achievement, or a more heart-warming expression of personal regard. It is, of course, impossible even to attempt, within any reasonable limits, a systematic review of a work so richly composite. The component articles are, naturally, of various lengths, styles, manners, and essential contents, from miniature monographs on particular documents from antiquity, on local schools, systems, or societies, or on periods of special scientific or medical developments, to revised interpretations of well known philosophical systems, and even to direct recollections of eminent teachers and investigators of recent times. It may be permissible, perhaps, to say a word of special welcome to

this latter recognition of the potential value, to the future historians of medicine and science, of such intimate reminiscences of the men who, in the contemporary judgments of their pupils and admirers, seem likely to retain such important stature in the longer perspective of future appraisal.

The book opens with an admirable sketch of Charles Singer's life by the editor. It will be of great interest to many to learn that Singer began his scientific career as a practical research worker in pathology, both in England and, later, after his marriage, for a period in Germany; and that, in his researches on cancer, he appears to have been only just anticipated, by another investigator, in a discovery which earned the award of a Nobel Prize. It is of interest also to recognize the determinant effects, on his eventual embarkation on a career which this book has been produced to celebrate, of his marriage to Dorothea Waley Cohen and of the recognition of the natural line of his genius by Sir William Osler.

As for the rest of the book's rich variety of learned and attractive contents, there are many articles presenting the results of historical and scholarly researches of great intrinsic importance, such as that by Leake, Larkey, and Lutz on 'The management of fractures according to the Hearst Papyrus'; by Wickersheimer (in French) on the medical texts of Chartres of the 9th, 10th, and 11th centuries; by Rabin on an Arabic text dealing with the skeleton by Ibn Jami', the Jewish physician to Saladin, Sultan of Egypt in the 12th century; and a great range of others of comparable interest and importance. It is, of course, impossible to mention all, or to pretend even to make a representative selection, where each is of such separate and individual interest, and all are of so high a standard. It must be sufficient, however invidious, just to name one which happens to have struck the reviewer's wayward fancy, from each of the other 'books', representing successive periods, into which the editor has divided the whole work. Thus, from Book III (The Renaissance), we select Cole's 'History of Albrecht Dürer's Rhinoceros', profusely and admirably illustrated; from Book IV (The New Philosophy), A. W. Mayer's 'The Elusive Human Allantois in Older Literature'; from Book V (The Insurgent Century), Le Fand's 'Jean Martet,

a French Follower of William Harvey'; from Book VI, Underwood's 'Von Berger and his Text-Book of Human Physiology'; from Book VII (The 19th Century and After), Cave's 'Richard Owen and the Discovery of the Parathyroid Glands'; and from Book VIII (*Conspectus Generales*), Darlington's racily critical 'Purpose and Particles in the Study of Heredity.' These are just random samplings indicative of the richness offered in these splendid volumes.

The editor and the Oxford University Press have done their parts admirably to ensure a really worthy presentation of this collection of testimonial offerings. A detailed textual criticism of such a work would demand months, or years, of study. Just because it catches the eye, a small error in the legend to Professor Franklin's sketch-portrait of the late Ernest H. Starling may be mentioned. His friends would have wished Starling to be knighted; but he never was. There is a full bibliography of Charles Singer's writings (over 410 items), and a very complete index. Altogether a noble tribute to a life of great scholarly achievement and inspiring leadership.

H. H. DALE

LOUIS PASTEUR

Un Maître de l'Enquête Scientifique, Louis Pasteur, by J. Nicolle. Pp. 222. Editions du Vieux Colombier, Paris. 1953. Fcs 610 net.

The author of this book set out—and succeeded perfectly in his aim—to reveal the mental processes which guided that incomparable 'magician' Pasteur in the great researches which occupied his life. Such an exposition of his reasoning makes apparent both its rigour and its admirable simplicity. Further, it reveals a unity in Pasteur's publications despite the diversity of their topics, which range from crystallography through fermentation processes to contagious diseases. Many readers will share the experience of the writer of the preface, P. Lépine: they too will find a lively pleasure in following the 'why and how' of Pasteur's reasoning, and reading this book should prove an excellent prelude to the vocation of research.

There are separate accounts of ten different inquiries—tartaric acid; fermentations; so-called spontaneous generation; vinegar; wine; silk; beer; carbon; chicken-cholera; and rabies.

R. DELABY

ORGANIC CHEMICAL DICTIONARY
Dictionary of Organic Compounds.
Editors-in-chief: Sir Ian Heilbron and H. M. Bunbury. Editors: A. H. Cook and E. R. H. Jones. New edition in four volumes. Pp. 654, 845, 838, and 694 respectively. Eyre and Spottiswoode Limited, London. 1953. £28 net.

This completely new and considerably augmented edition of Heilbron's 'Dictionary' will be welcomed by all organic and biological chemists. Those who have not ready access to Beilstein's *Handbuch* will find this work extremely useful for very many purposes, though obviously not completely exhaustive in its scope. Even chemists who have access to all the members of the rapidly increasing Beilstein family will—when pressed for time or in moments of physical or mental exhaustion—turn to this dictionary in the hope of finding quickly some leading reference, some physical constant or structural formula. Human nature being what it is, these occasions will be frequent, and the seeker will very often be rewarded by finding exactly what he wants.

Having regard to the limits which the compilers have set themselves it is impossible to speak too highly of the results of their labours. The arrangement is alphabetical, and where this simple system might be expected to become complicated the difficulties are smoothed away by the enunciation of a few guiding principles, illustrated by formulae showing straight and branched chains and ring systems with numbered carbon atoms. The introduction contains a list of the names and formulae of the principal substituents, and the titles (full and abbreviated) of the 145 journals to which references are made.

The information that is usually given for each substance cited includes the full structural formula (where known), melting-point, boiling-point, appearance, solubility, natural occurrence, and from two to six (and sometimes more) references. Over 2500 new compounds have been added since the last edition, and the literature has been surveyed up to the end of 1950. Many references from the years 1951–3 are, however, included, those of biochemical significance having received special attention.

Chemists who are working in the field of natural products will particularly welcome the success with which the alphabetical system enables details of the most varied substances, often having most unusual and attractive

structures, to be found with the greatest ease. The information provided in this field is most comprehensive and stimulating, and will be found invaluable. Thus, by chance, the reviewer came across a reference to thevetose, an example of the natural partially methylated sugars, very few of which have come to his notice.

On the other hand, there seems to be no mention of any of those carboxylic derivatives of alkyl or alkylarylsulphonium salts which, under the historic name of thetins, have recently attracted attention in America, where the group name is becoming widely used. Several of the tropolones are cited, however, and also the remarkable heterocyclic sulphur compound thia-adamantane, recently isolated from petroleum by Birch and his colleagues. The no less interesting parent compound adamantane, another petroleum product, also finds a place along with the hormones A.C.T.H., corticosterone, and cortisone; streptomycin, actinomycin, and atebirin (better known as mepacrine, the antimalarial drug) are also cited. The penicillins and their degradation products occupy seven pages.

Research workers in synthetic organic chemistry, and those concerned with the intermediate products of the dyestuff industry, will find that their needs have been carefully considered. The book is useful and labour-saving, but is also a valuable contribution to chemical literature and a source of intellectual stimulus and satisfaction to those who can 'turn but a stone and start a wing.'

FREDERICK CHALLENGER

THE CRYSTALLINE STATE

The Determination of Crystal Structures, by H. Lipson and W. Cochran. Pp. ix + 345. G. Bell and Sons Limited, London. 1953. 50s. net.

This book is the third and final volume of the important series on 'The Crystalline State,' edited by Sir Lawrence Bragg. It takes up the problem of structure determination from the point at which the experimental work has been completed, and since it contains a discussion of the reliability of final results in terms of the accuracy of the experimental measurements, it will not become outdated by improvements in experimental technique.

The authors have themselves made, and are still making, outstanding contributions to the subject in both theory and practice, and the inclusion in a book published in 1953 of references to

papers published in the same year is a striking indication of the fact that even the specialist could gain little more by consulting newly published papers. Indeed, the mathematical nature of much modern theory concerning the solution of the phase problem in crystal structure analysis has meant that individual contributions, written with varying degrees of clarity and differing nomenclatures, have often appeared more formidable than the admirably unified presentation in this book shows them to be.

We cannot be too grateful to the authors for rendering such a signal service to all those interested in structural crystallography. While they rightly remind us that there is no substitute for experience in successful structure determination, this book is the nearest thing to a substitute that we are likely to find.

KATHLEEN LONSDALE

FLAMES

Flames. Their Structure, Radiation and Temperature, by A. G. Gaydon and H. G. Wolfhard. Pp. 340, with half-tone and line illustrations. Chapman and Hall Limited, London. 1953. 55s. net.

Combustion reactions have been studied so extensively by chemists and physicists, and their technical importance is so great, that today they can hardly be presented within a single treatise. In this book, of moderate size, the authors have restricted the scope to 'stationary flames, with the emphasis on the physical rather than the chemical viewpoint.' Further, they have especially concentrated on 'the measurement of flame velocity, the theories of flame propagation, the method of carbon formation in flames, flame radiation, the measurement of high flame temperatures and ionization in flames.'

It is obvious from this survey that the field covered is still very wide, and the guidance of the two authors, who have a great number of original contributions to their credit, will be very welcome to many. The book is richly illustrated with figures, diagrams, photographs of spectra, and a few coloured pictures of flames.

To avoid the impression that the book is confined to the subjects singled out by the authors in their preface, it should be mentioned that a few short, but highly instructive, paragraphs are also devoted to isolated subjects like sensitive flames; flames containing nitrogen oxides, diborane, or fluorine; atomic flames; and the combustion of

solid particles. These few hints must suffice to indicate the wealth of material the book offers. F. A. PANETH

NUCLEAR PHYSICS

Experimental Nuclear Physics, edited by E. Segre. Volumes I and II. Pp. 789 and 600 respectively. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1953. 120s. and 96s. net.

'A cooperative effort like the Geiger-Scheel *Handbuch der Physik* seemed the only solution,' comments the editor of this three-volume work on nuclear physics (the third volume is still to be published). The high standard implied by this comparison is brilliantly maintained throughout a series of contributions, each written by an authority. Topics covered are detection methods; passage of radiation through matter; nuclear moments and statistics; nuclear two-body problems and elements of nuclear structure; charged particle dynamics and optics; relative isotopic abundances of elements; atomic masses; nuclear reactions; the neutron. From a work of such encyclopaedic character it would be invidious to single out individual contributions and impossible to do equal justice to all. Suffice it to say that the present reviewer studied those parts in which he feels himself competent to look for mistakes, and found very few—and those trivial ones.

Although the title of this work contains the word 'experimental', it would be wrong to assume that this is a mere catalogue of experiments. Each account is set firmly against its background of theory, and the work as a whole contains more theory than any book on theoretical nuclear physics except that by Blatt and Weisskopf, to which it would appear to be a companion. The experiments are clearly written and excellently illustrated with diagrams, graphs, and tables, and the whole is so beautifully produced that it is difficult to cavil at its price. L. R. B. ELTON

SYMBIOSIS

Endosymbiose der Tiere mit Pflanzlichen Mikro-organismen, by Paul Buchner. Pp. 772. Verlag Birkhäuser, Basle. 1953. Paper covers, Sw. fcs 62.40; bound, Sw. fcs 66.50 net.

In this excellent book Dr Buchner correlates much general knowledge with the results of his own 40 years' study of symbiosis. The work is divided into three main parts. The first deals with the discovery and extent of endosymbiosis. The second, special, part des-

cribes the various symbiotes, their form, biology, and host relationships, etc. Here the grouping is based neither on the systematics of the hosts, nor on that of the symbiotes themselves, but on the food or physiology of the hosts. Seven main groups are recognized: symbiotes in animals feeding respectively on materials rich in cellulose, on tree fluxes, on plant sap, on keratin, and on mixed foods; those in animals capable of producing light; and those which are restricted to the excretory organs.

The third, general, part discusses the location of symbiotes, the means by which they are transferred to the next generation, their development during the embryonic and post-embryonic periods of the host, and the economics of their association. Here also is discussed the part symbiotes can play in elucidating the evolutionary history of the hosts. The work is very clearly written and copiously illustrated.

F. BARANYOVITS

ORGANIC ANALYSIS

Estimation of Organic Compounds, by F. Wild. Pp. 239. Cambridge University Press, London. 1953. 25s. net.

No book on quantitative organic analysis has been published in Britain since Thorpe and Whiteley's 'Organic Chemical Analysis' in 1925: this is now out of date and has long been out of print. The publication of Dr Wild's book is therefore timely.

The volume is divided into seven chapters: olefines—solid, liquid and gaseous; alcohols, enols, and phenols; mercaptans; aldehydes and ketones; amines and amino compounds; nitro, nitroso, and cyano compounds, isocyanates and isothiocyanates; other groups including acetyl, benzoyl, methoxyl, ethoxyl, propoxyl, butoxyl, methylimino, ethylimino, methyl and ethyl groups attached to sulphur, and methyl groups attached to carbon. The ultimate analysis of organic compounds is not discussed. The various methods for determining the different groups are described in varying detail, the sources of error are mentioned as well as means for eliminating them or reducing them to a minimum; the percentage accuracy is given for those procedures which are described in full. The author has not hesitated to make use of physical methods where applicable. Literature references are given throughout.

As Dr Wild points out in his preface, quantitative organic analysis is rarely dealt with adequately in the teaching

of chemistry, and there can be little doubt that his book will help to stimulate interest in this subject. The book should prove of great value to students in the final years of the honours degree course and to research workers in organic chemistry.

A. I. VOGEL

METEOROLOGY IN HOLLAND

Koninklijk Nederlands Meteorologisch Instituut 1854-1954. Centenary Celebration Volume published by the Royal Netherlands Meteorologica Institute. Pp. 469, with colour, half-tone, and line illustrations. Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage. 1954. N.p.

For two quite practical reasons, there was a great upsurge of interest in meteorology in the middle of the nineteenth century. The first reason was the realization that application of contemporary knowledge about ocean winds could materially reduce the times of passage of the great clipper sailing-ships. The second was a determination to try to warn shipping of the existence of tempestuous winds. So it was that most of the maritime nations of the world founded their state meteorological services in the 1850's. The Dutch were among the first to do so, and the service then founded has today had the happy thought of celebrating its centenary by producing a magnificent volume telling the history of the service. It is a distinguished history, with a distinguished line of directors from Professor Buys Ballot, the founder, to Professor Vening Meinesz, the last to have completed his term of office.

The book is in three parts. The first is largely historical, with notable sections on the work undertaken in international meteorology, including the international polar years 1882-3 and 1932-3. The second is on the present structure and activities of the service, the activities including not only meteorology but physical oceanography and most other parts of geophysics. Finally, there are ten original papers on fields of geophysical research in which present members of the service are particularly active. One of these papers, appropriately enough, surveys the evidence on climatic change from the instrumental records at De Bilt over the last 200 years. The book is beautifully illustrated, partly with coloured plates showing various states of the sky, and is a service to science as well as a homage by the present Dutch service to its forebears. P. A. SHEPPARD

(Note. Mention of a book on this page does not preclude subsequent review.)

BIOLOGY

Animal Biochromes and Structural Colours, by Denis L. Fox. Pp. 379. Cambridge University Press, London. 1954. 60s. net.

Freshwater Microscopy, by W. J. Garnett. Pp. 300. Constable and Company Limited, London. 1954. 30s. net.

An Introduction to Bacterial Physiology, by Evelyn L. Oginsky and Wayne W. Umbreit. Pp. 416. W. H. Freeman and Company, San Francisco; Bailey Brothers and Swinfen Limited, London. 1954. 51s. net.

Microbiology, An Introduction, by Ernest A. Gray. Pp. 175. Crosby Lockwood and Son Limited, London. 1954. 10s. 6d. net.

Résistance et Soumission en Physiologie, by H. Laborit. Pp. 120. Masson et Cie., Paris. 1954. Fcs 650 net.

CHEMISTRY

L'Analyse Spectrale Quantitative par la Flamme, by R. Mauvrodineanu and H. Boiteux. Pp. 247. Masson et Cie., Paris. 1954. Paper covers, fcs 3800; bound, fcs 4300.

Catalysis, Volume I, edited by Paul H. Emmett. Pp. 394. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1954. 80s. net.

Chimiosynthèse et Photosynthèse, by Roger Buwat. Pp. 208. Presses Universitaires de France, Paris. 1954. Fcs 720 net.

Les Constantes Physiques de Composés Organiques Cristallisés, by J. Timmermans. Pp. 558. Masson et Cie., Paris. 1954. Fcs 5200 net.

French-English Dictionary for Chemists (2nd edition), by Austin M. Patterson. Pp. 476. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1954. 52s. net.

The Infra-red Spectra of Complex Molecules, by L. J. Bellamy. Pp. 323. Methuen and Company Limited, London. 1954. 35s. net.

Isotopic Tracers, by G. E. Francis, W. Mulligan, and A. Wormall. Pp. 306. The Athlone Press, London. 1954. 37s. 6d. net.

Lehrbuch der Organischen Chemie (12th edition, revised), by Paul Karrer. Pp. xx + 949. Georg Thieme Verlag, Stuttgart. 1954. DM 59.70 net.

Methoden der Organischen Chemie (Houben-Weyl) 4th revised edition, edited by Eugen Müller. Georg Thieme Verlag,

Stuttgart. Vol. II: Analytische Methoden. Pp. xxiv + 1070. 1953. DM 139 net. Vol. VII, Part 1: Sauerstoffverbindungen II, Aldehyde. Pp. xxiii + 596. 1954. DM 82 net. Vol. VIII: Sauerstoffverbindungen III. Pp. xviii + 776. 1952. DM 98 net.

Qualitative Inorganic Analysis, by G. Charlot. Pp. 354. Methuen and Company Limited, London. 1954. 42s. net.

Quantitative Organic Analysis via Functional Groups (2nd edition), by Sidney Siggia. Pp. 227. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1954. 40s. net.

Semi-Micro Organic Preparations, by J. H. Wilkinson. Pp. 94. Oliver and Boyd, Edinburgh. 1954. 8s. 6d. net.

The Structures and Reactions of the Aromatic Compounds, by G. M. Badger. Pp. 456. Cambridge University Press, London. 1954. 63s. net.

Vegetable Fats and Oils, by E. W. Eckey. Pp. 836. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1954. 132s. net.

GENERAL

Discovery Reports, Vol. XXVI; Open Boat Whaling in the Azores, by Robert Clark. Pp. 281-324. Cambridge University Press, London. 1954. 21s. net.

A Discussion on the Maintenance of Cultures by Freeze Drying. British Commonwealth of Nations Scientific Liaison Offices. Pp. 48. Her Majesty's Stationery Office, London. 1954. 5s. net.

Instrumental Analysis, by John H. Harley and Stephen E. Wiberley. Pp. 440. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1954. 52s. net.

The Steel Skeleton, Volume I: Elastic Behaviour and Design, by J. F. Baker. Pp. 206. Cambridge University Press, London. 1954. 42s. net.

HISTORY OF SCIENCE

Astrology and Alchemy, by Mark Graubard. Pp. 382. Philosophical Library, New York. 1953. \$5 net.

Im Banne der Chemie; Carl Bosch, Leben und Werk, by Karl Holdermann. Pp. 336. Econ-Verlag, Düsseldorf. 1954. DM 14.80 net.

MEDICAL

Deutsch-Englisches, Englisch-Deutsches Wörterbuch für Ärzte (in two volumes),

Volume I, by F. Lejeune; Volume II, by F. Lejeune and W. E. Burges. Pp. xx + 1352 and xl + 1737 respectively. Georg Thieme Verlag, Stuttgart. 1951 and 1953. DM 24 and 58.50 respectively.

Physiological Acoustics, by Ernest Glen Wever and Merle Lawrence. Pp. 454. Princeton University Press, Princeton; Geoffrey Cumberlege, London. 1954. 80s. net. Praktische Arbeitsphysiologie, by Gunther Lehmann. Pp. 355. Georg Thieme Verlag, Stuttgart. 1953. DM 33 net.

METALLURGY

Engineering Steels, by Leslie Aitchison and William I. Pumphrey. Pp. 923. Macdonald and Evans Limited, London. 1953. £5 5s. net.

The Structure of Metals and Alloys, by William Hume-Rothery and G. V. Raynor. Pp. 363. The Institute of Metals, London. 1954. 35s. net.

Text-book of Metallurgy, by A. R. Bailey. Pp. 560. Macmillan and Company Limited, London. 1954. 30s. net.

PHYSICS

L'Instabilité en Mécanique, by Y. Rocard. Pp. 240. Masson et Cie., Paris. 1954. Fcs 1200 net.

Le Microscope à Contraste de Phase et le Microscope Interférentiel, by Maurice Françon. Pp. 149. Editions du Centre National de la Recherche Scientifique, Paris. 1954. Fcs 1000 net.

Numerical Tables of Nuclear Physics, by Charles Noël Martin (French and English texts). Pp. 258. Gauthier-Villars, Paris. 1954. Bound, 44s. 11d.; unbound, 36s. 9d. net.

The Quantum Theory of Radiation (3rd edition), by W. Heitler. Pp. 430. Oxford University Press, London. 1954. 45s. net.

Théorie Générale des Particules à Spin (Méthode de Fusion), by Louis de Broglie. Pp. 209. Gauthier-Villars, Paris. 1954. Fcs 2500 net.

TECHNOLOGY

Minerals for the Chemical and Allied Industries, by Sydney J. Johnstone. Pp. 692. Chapman and Hall Limited, London. 1954. 75s. net.

The Post-War Expansion of the U.K. Petroleum Industry, edited by George Sell. Pp. 220. The Institute of Petroleum, London. 1954. 25s. net.

SIR ROBERT ROBINSON,
O.M., M.A., D.Sc., LL.D., F.R.S.,

Was born in 1886 and was educated at Fulneck School, near Leeds, and the University of Manchester. Appointed professor of organic chemistry in the University of Sydney in 1912, he has since held several professorial chairs, and since 1930 has been Waynflete Professor of Chemistry in the University of Oxford. His scientific work has been concerned with the structure and synthesis of such natural products as alkaloids and anthocyanins, and with the application of electronic theories to the mechanism of reaction. He has been President of The Royal Society and of The Chemical Society, and is a medallist of these and many other learned bodies. He is President-elect of the British Association for the Advancement of Science.

A. URBAIN,
Docteur-ès-Sciences,

Was born at Le Havre in 1884, and became a veterinary surgeon in the army in 1906. Continuing his studies of natural science, he obtained his doctorate in 1920. He joined the *Muséum National d'Histoire Naturelle* in 1931, and two years later was appointed director of the collections of living animals. In 1942 he was elected Director, and is now Honorary Director. The flourishing state of the zoological gardens in the *Parc Zoologique du Bois de Vincennes* is largely due to his personal efforts.

J. C. G. NOUVEL,
Licencié-ès-Sciences,

Was born at Nantes in 1909, and obtained the diploma of doctor of veterinary science in 1931; he then continued his studies at the Faculty of Sciences and became *Licencié-ès-Sciences* in 1937. He joined the *Muséum National d'Histoire Naturelle* in Paris in 1935 as assistant to the professor of ethology of wild animals, and has collaborated since that date with Professor Urbain. He was appointed *Sous-directeur* of the laboratory of the *Muséum* in 1947.

H. GREINACHER,
Dr. Phil.,

Was born in Switzerland in 1880 and was educated at the University of Berlin graduating in 1904. Subsequently he was assistant in the universities of Berlin, Heidelberg, Geneva, and Zürich. At the latter he was appointed lecturer in 1907 and professor of radiology in 1916. In 1924 he was appointed Professor of Physics and Director of the Physics Institute and Meteorological Observatory, University of Bern, appointments which he held until his retirement in 1952. Has carried out much work, chiefly experimental, in various fields of physics, particularly in those relating to high-tension and measuring technique.

E. GÄUMANN,
Ph.D.,

Was born at Lyss, Switzerland, in 1893, and graduated from the University of Bern in 1917; he afterwards studied for a year at the University of Uppsala. From 1919 to 1922 was plant pathologist in the agricultural department, Dutch East Indies; 1922-5, botanist at the Swiss Agricultural Experimental Station at Zürich-Oerlikon. In 1925 he was appointed Lecturer in the Institute for Special Botany of the Swiss Federal Institute of Technology at Zürich; two years later he was appointed Professor and Director. He has an international reputation as a plant pathologist.

W. H. MILLS,
M.A., Sc.D., F.R.S.,

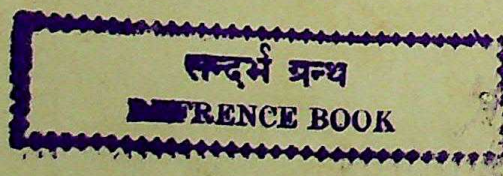
Was born in 1873 and was educated at Uppingham School and the Universities of Cambridge and Tübingen. Is Emeritus Reader in Stereochemistry at Cambridge, where he is a Fellow, and during the years 1940-8 was President, of Jesus College. Is a Davy Medallist of The Royal Society, and a Longstaff Medallist of The Chemical Society, of which he was President 1941-4.

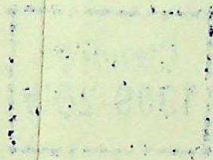
M. S. HORNING,
M.A., D.Sc.,

Was born at Sydney, Australia, in 1900, and is a graduate of the universities of Oxford and Melbourne. In the war of 1914-18 he served with the Australian Imperial Forces. During the tenure of a Rockefeller Medical Research Fellowship he worked at the *Kaiser Wilhelm Gesellschaft* in Berlin-Dahlem, at other research centres in Europe, and later at the Washington University Medical School, St Louis. In 1933 he was awarded a Beit Medical Research Fellowship and returned to London to work at the Imperial Cancer Research Fund Laboratories, where he later became a member of the scientific staff. During the last war he served with the Royal Naval Volunteer Reserve. At the conclusion of the war he was appointed to the Readership in Experimental Pathology, tenable at the Royal Cancer Hospital. His numerous publications have been mainly in the sphere of experimental pathology.

E. KUHN-SCHNYDER,
D.Sc.,

Was born at Zürich in 1905, and studied natural science at the Federal Technical High School there, graduating in zoology in 1932. From 1931 to 1940 he was chief teacher of mathematics and natural sciences, and later principal, in the Regional School at Bremgarten. In 1940 he became senior assistant at the Zoological Museum, and in 1947 lecturer in comparative anatomy and palaeontology at the University of Zürich. Since 1950 he has been directing an extensive new excavation on Monte San Giorgio. He is author of *Die Tierwelt der prähistorischen Siedlungen der Schweiz* (with the late K. Hescheler, 1949), *Die Geschichte der Wirbeltiere* (1953), as well as of many articles on palaeontological research.





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